THE ROMANCE OF MODERN ASTRONOMY

HALLEY'S COMET, 1910

To the ordinary observer this comet has proved a failure as a popular spectacle. But as seen through a powerful telescope it has been far from disappointing. This illustration has been made from a drawing at Greenwich Observatory. It represents the aigrette or fan spreading forward from the nucleus in the direction of the comet's motion.

THE ROMANCE OF MODERN ASTRONOMY

DESCRIBING IN SIMPLE BUT EXACT LANGUAGE THE WONDERS OF THE HEAVENS

BY

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PREFACE

IN the preparation of this volume the writer has received invaluable assistance from several well-known astronomers. His special thanks are due to Mr. J. E. Gore and Mr. E. W. Maunder for their kindness in reading over and correcting the proof-sheets, and for their useful suggestions; to Professor Percival Lowell for the two views of Mars and for the photograph of Saturn; and to Professor Max Wolf for the beautiful photographs of stars and nebulæ which are reproduced here by his kind permission.

Finally, the writer has to mention the kindness of Professor Schiaparelli for furnishing one of his classical drawings of Mars, and for permission to reproduce it in this book. Since that permission was granted, Professor Schiaparelli's death has bereft astronomy of an illustrious leader.

July 1910.

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CHAPTER I

OUR PLACE IN THE UNIVERSE

SCIENCE is the study of Nature. By means of science we are enabled to understand the everyday things of life—the flowers, the hills, the stars—and the place which they occupy in Nature. Thus, botany is the study of the flowers and trees; geology is the study of the hills and rocks; while astronomy raises our thoughts to the star-spangled heavens.

Of all the sciences—and they are many and varied—astronomy is the most interesting and the most wonderful. Not only is it full of interest, but it is in many ways the most educative study which the human mind can pursue; for it enables us to understand the position which our world occupies in the Universe. By astronomy men were enabled to answer the question, "What is the Earth?"

In childhood we learn that "the Earth is round like an orange or a ball," but when we stand out in the open and look around us, the Earth seems more like a vast illimitable plain than a round globe. Long ago, in the childhood of the race, men believed our world to be a vast

illimitable plain, but reflective minds were not satisfied with this theory. They soon perceived that the Earth was not a plain. The Sun, it was observed, rose in the east every morning, and set in the west every evening, and it was obvious that it could not rise and set through the solid ground. The question presented itself to those early Chaldean and Greek students of Nature,—Where did the Sun go every night? Did it pass under the Earth? Such an idea was unthinkable to those early scientists. Was not the Earth solid and immovable, firmly fixed at the bottom of Creation? Accordingly some very remarkable theories were devised to explain how the Sun rose in the east in the morning, after having disappeared in the west the previous evening. Some of the ancients believed that the Sun fell into the sea at night and was quenched, and that the gods were busy all night making a new Sun to start the next morning in the east. But, as Sir Robert Ball remarks, "this was thought to be such a waste of good Suns that a more economic theory was afterwards proposed." This was that, as the Sun was falling into the ocean in the west, it was caught by the god Vulcan, who was waiting in his boat to prevent it falling into the sea. Having placed the orb of day in his boat, Vulcan rowed round by the north, where a great ocean was supposed to exist. Arriving in the east, he pitched the Sun into the sky with tremendous force, to commence another day's journey.

Theories such as these had influence for many years over the minds of men. Gradually, however, it became apparent that such ideas were absurd, and that the Sun must really go below the Earth. And here students of Nature asked—What is the Earth, and what supports it? Many grotesque theories were put forward. One

speculator thought that the Earth was held up by great pillars, which allowed the Sun to pass between them; another believed our world to be supported by enormous mythical animals. Some support, in the minds of the ancients, was absolutely necessary. The author of the Book of Job, however, had grasped the truth, for, writing of the power of the Creator, he says, "He hangeth the Earth upon nothing."

This is literally true; the Earth hangs upon nothing. Gradually the truth dawned that the Earth was a globe, not a vast plain—a view which was held by the great Greek philosopher, Aristotle, and became generally accepted. Aristotle thought that the Earth, a globe suspended in space, was the centre of the universe, round which the Sun, Moon, and stars revolved. By this time considerable progress had been made in the study of astronomy. The study of the stars had become a science of measurement, and it was soon apparent that the celestial bodies had not one motion round the Earth only, but a number of motions. For instance it was known that the Sun, Moon, and stars revolved round the Earth every twenty-four hours. But it soon became apparent, as observation progressed, that the Moon had another motion round the Earth once in a month; and that the Sun seemed to have also another motion, revolving round the Earth once in a year. Then attentive observation of the heavens disclosed the existence of another class of objects. The ordinary stars—"fixed stars" as they came to be called—revolved once in twenty-four hours. But they did not change their positions relative to each other. The star-groups or constellations remained unchanged. The early astronomers noted that there were five bright star-like objects, which, instead of remaining fixed in the sky,

moved in an irregular manner round the heavens, always keeping close to the path traversed by the Sun on its annual journey. These the early observers named "planets," which is Greek for "wanderers." It was soon recognised that there were five of these objects, each different from the other. There was Venus, the brightest of the wanderers, shining with a soft, gentle, steady light, named by the ancient Greeks after their goddess of love. They noticed that Venus never moved far from the Sun—that it was never to be seen shining on a really dark sky. It was also observed that Venus was sometimes visible as an evening star after sunset, and sometimes as a morning star before sunrise. Indeed it was long thought that the morning star and the evening star were separate bodies; but very early in astronomical history it was recognised that they were one and the same. The ancients recognised another bright object also visible as an evening and morning star, and keeping much closer to the Sun than Venus. They called the planet Mercury, "the messenger of the gods." But they also called it "the sparkling one," from its rapidly twinkling light. Another bright object, much brighter than Mercury, was also recognised—a great golden star, which, instead of keeping close to the Sun, swept majestically round the entire heavens. This they named Jupiter after their chief deity. Then they recognised a planet of reddish hue which at times waxed almost as bright as Jupiter, then rapidly waned. From its fiery colour they named this object Mars, after the god of war. Yet another planet, fainter than the rest—slow moving—of a dull yellowish light, creeping round the entire heavens once in about thirty years, was named Saturn, after the god of time.

Each of these planets had its own peculiarities of

motion, and partook also in the revolution of the entire heavens once in twenty-four hours. The problem before the ancient astronomers then was how to account for the motions of Sun, Moon, planets, and stars. Many and varied were the explanations put forward. Eudoxus, a Greek thinker who died about 355 B.C., was the author of an ingenious attempt to explain these motions by an elaborate theory known as that of the spheres. The Earth, he believed, was a globe firmly fixed at the centre of the universe. Each planet was fixed to a number of different spheres by the manipulation of which the elaborate motions resulted. Then at the extreme limit of the universe was a sphere to which all the stars proper were fixed.

Another theory was that of the astronomer Hipparchus, which was developed to its greatest extent by his successor, Ptolemy, of Alexandria, in Egypt. Like Eudoxus, Ptolemy believed that the Earth was firmly fixed as the centre of creation. But he did not accept the theory of spheres. He believed that the Sun, Moon, planets, and stars revolved round the Earth in the following order—the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the stars proper, which, as in the theory of Eudoxus, were supposed to be attached to the inside of a large sphere. But Ptolemy was not ignorant of the irregularities in the motions of the planets, of the fact that the planets did not move with uniform velocities. He was one of the most thoughtful of the ancient astronomers, and he knew that if a planet moved round the Earth in a uniform circular orbit, its velocity and direction would not change. Accordingly he devised a most complicated and ingenious theory—that the planets moved in circles, and that the centres of these circles revolved round the Earth in larger circles.

The smaller circles were called epicycles. As new irregularities came to be discovered, new epicycles had to be invented, until at last the theory became so difficult and cumbersome that few could understand it. Indeed it is recorded of a certain King of Spain that when his tutor was explaining to him the theory then generally accepted, he exclaimed in disgust that if he had been consulted at the Creation, he could have given some useful hints for simplifying the system of the Universe.

In spite of the intricacies and improbabilities of Ptolemy's theory, it was accepted for fourteen hundred years. It is true that some keen minds among the Greeks had come to the conclusion that there was a much simpler conception of the Universe; but they had not the courage to declare for a new theory, and it was left for Nicolaus Copernicus, a Polish clergyman, to propound the system which bears his name. Copernicus, after giving deep attention to the subject, came to the conclusion that it was much easier to believe that the Earth turned on its own axis, and so caused an apparent motion of Sun, Moon, planets, and stars, than to think that these objects all happened by some coincidence to go round our planet in exactly the same time. Copernicus also came to the conclusion that, instead of the Sun moving round the Earth once a year, and the planets also revolving round our world in complicated orbits, it was more reasonable to believe that the Earth and the other planets revolved round the Sun. This was the theory which Copernicus put forward. It had the merit of simplicity, but notwithstanding this fact, it was disbelieved, and its supporters were threatened with persecution. Nevertheless, men of science were driven to accept it, because they saw how

greatly its acceptance simplified the complicated motions of the planets. Tycho Brahe, the famous Danish astronomer, abandoned the idea that the planets revolved round our Earth, choosing to believe that they revolved round the Sun, which moved round our planet. The next step was to declare boldly that the theory of the Earth's motion explained more satisfactorily the motions of the celestial bodies. This step was taken by Bruno, Galileo, and Kepler. But it was taken at a great risk, and at a great sacrifice. Bruno was burned alive for holding this theory among others which the Roman Catholic Church had pronounced to be impious. Galileo had to suffer much persecution for his championship of the Copernican theory. Its opponents disliked Galileo most of all, because he brought forward unanswerable arguments in favour of the new system. Kepler, the least persecuted of the three, was destined still further to improve the theory by his famous "three laws." He showed that the Earth and the other planets, instead of revolving round the Sun in circular paths, moved in ellipses. He was enabled to explain many of the irregularities which Copernicus had to leave unsolved. Thus the labours of Copernicus, Galileo, and Kepler showed us beyond a doubt our true position in the universe—that the Earth is merely a planet in constant revolution round the Sun, a member of the Sun's system, and a companion planet of Mercury and Venus, Mars, Jupiter, and Saturn.

It was Sir Isaac Newton who demonstrated beyond doubt the truth of the system of Copernicus. Newton furnished mankind with a key to unlock the mysteries of the Solar System; he explained why the Earth and the other planets were constantly moving round the Sun,

and why they moved in elliptical orbits. It was in the year 1666, when Newton was a young man in his ancestral home near Grantham, in England, that his mind first lit on the grand idea of the law of gravitation—that every particle of matter in the universe attracts every other particle. The story goes that one day when Newton was sitting in his garden he saw an apple fall to the ground. Now, he knew why the apple fell—because it was heavy; in other words, because it was drawn to the Earth by the power of gravitation. And he was led to ask if the same force did not keep the Moon in its monthly orbit round the Earth, and prevent it flying off into space, and also keep the Earth and the other planets in their paths round the Sun. After twenty years' hard mathematical work, he was able to prove that the force which drew the apple to the ground held the Moon in its orbit; and that the Moon moved round the Earth, and the Earth and the other planets round the Sun, simply by virtue of the inherent power of gravity in these various bodies. For instance, the Earth attracts the Moon, and the Moon attracts the Earth; but the Earth is so much larger than the Moon that our satellite is compelled to revolve round our world. Similarly the Sun attracts the Earth, and the Earth attracts the Sun, but owing to the immense superiority of the Sun in size, the Earth, though having a natural tendency to move in a straight line, is compelled to move round the larger body.

Thus Copernicus showed us our Earth's position in the Solar System, and Newton showed us why we occupy that position. The result of the change in astronomical thought was that the Earth's inhabitants could no longer

consider themselves the chief objects of creation. Our world was brought down from the position of ruler and centre of the universe to the humble place of a small planet revolving round the Sun. As we shall find in the following chapters, this was but the first step in the change of opinion, for the researches of Sir William Herschel and later astronomers have proved that our planet is a mere grain of sand in the ocean of infinity. Astronomy enables us to understand the fact—though we but imperfectly realise it—that our Earth, which seems to us a great flat immovable plain, is in reality a globe about 8000 miles in diameter, turning on its own axis in twenty-four hours, and dashing onward in its orbit round the Sun at the rate of eighteen miles a second. We do not feel the motion of our planet, because we are carried along with it, and the atmosphere is also a component part of our globe. It is difficult to grasp the fact that our planet is moving onwards with so great a velocity, that each second of time finds us eighteen miles onward on our journey. Thus we see that astronomy, alone of the sciences, answers the question—What is our Earth, and what is its position in Nature?

CHAPTER II

EFFECTS OF THE EARTH'S MOTIONS

THE motion of the Earth is the magic key which unlocks the door of the mysteries of the everyday phenomena of Nature. Day and night, the seasons, twilight, "the midnight Sun," the long polar night, all these phenomena are easily understood when we regard them in the light of the rotation of the Earth on its axis, the inclination of this axis, and the revolution of the Earth round the Sun.

To the first of these facts, the rotation of the Earth, we are indebted for the phenomenon of day and night. The Earth is constantly whirling round on its axis from west to east, and the result is the apparent motion of the heavenly bodies from east to west. By this motion of rotation we get the first and most obvious measure of time—the day which measures in length only a few minutes under twenty-four hours.

A good idea of the rapid rate at which the Earth is turning on its axis may be had by pointing a telescope to a star, and by noticing how swiftly the star passes out of the field of view. At sunrise and sunset, too, we notice plainly the difference made by a few minutes. Owing to the fact that the Earth has an atmosphere, daylight does not disappear whenever the Sun sinks below the horizon. The rays of the Sun still strike the upper regions of our atmosphere, and thus we have twilight and

the gradual darkening of the sky and disappearance of daylight.

The chief effect of the Earth's revolution round the Sun—an effect which affects the periods of light and darkness—is the change of the seasons, spring, summer, autumn, and winter. This ceaseless cycle, to which the Earth's inhabitants are so accustomed that they scarcely stop to ask themselves the why and wherefore, is due chiefly to one astronomical fact. The axis of the Earth—the imaginary line joining the north and south poles—is inclined to the orbit of our planet by about sixty-seven degrees. This explains the seasons and the differing lengths of day and night on the various parts of the Earth. Most of us have heard of such phenomena as the long polar night, the midnight Sun, &c., but few really understand that these phenomena are due to the same causes which give us our long periods of daylight in summer and of darkness in winter.

At the spring equinox, day and night are equal all over the world—at the poles and the equator. At this period both poles of the Earth are equally exposed to the solar rays. Neither is tilted towards the Sun more nor less than the other. But as the Earth moves gradually round, the northern hemisphere becomes more and more inclined towards the solar beams, while the southern hemisphere is more and more inclined away from the orb of day. Spring is giving place to summer. At the summer solstice the northern hemisphere is tilted towards the Sun at its greatest inclination while it is midwinter in the south. The days and nights were equal at the spring equinox; at the summer solstice the days are much longer than the nights in the northern hemisphere, the opposite being the case in the south. After the 21st of June the period

of darkness increases in the northern hemisphere and decreases in the southern, until on the 21st of September daylight and darkness are equal all over the globe. In its cycle of change the axis of the earth is again upright relative to the Sun. After the autumn equinox is past, the northern hemisphere tilts more and more away from the Sun, while the southern comes more and more into sunlight. The result is that by the 21st of December, when the winter solstice is reached, the northern hemisphere has a short period of daylight and a long period of darkness, while the reverse state of affairs takes place in the south. The northern hemisphere is tilted from the Sun at its greatest tilt. After the winter solstice the period of daylight increases in the northern hemisphere and decreases in the southern, until we come again to the 21st of March, when at the spring equinox day and night are equal all over the world.

In the early ages of the world, before astronomy had been developed, men did not understand this revolution of our dwelling-place round the Sun. They only knew, just as the unlearned know to-day, that at the winter solstice, in the middle of December, the Sun rose in the south-east, moved across the southern sky, rising to a low altitude above the horizon, and set in the south-west in the afternoon. We notice that after the solstice is past, the Sun rises a little earlier each morning and sets a little later each evening, that it rises farther east each morning, and sets farther west each evening, until on the 21st of March the orb of day rises exactly in the east and sets exactly in the west. Likewise we notice that as more and more is seen of the Sun, the Earth wakens out of its winter sleep. Trees begin to bud, grass to grow—in short, Nature revives. As one writer puts it: "The

melting of the ice and snow, the gradual reviving of brown soils, the flowing of sap through branches apparently lifeless, the mist of foliage beginning to enshroud every twig until the whole country is enveloped in a soft haze of palest green and red—all these are Nature's signs of spring."

Then as spring gradually passes into summer, the Sun rises every morning a little farther north, and sets every evening a little farther north, while every day it rises higher and higher in the sky. Then on the 21st of June, the "longest day," it rises north-east and sets north-west, and is about eighteen hours above the horizon. This is the period of longest daylight, because, as explained, the northern hemisphere is turned directly towards the Sun, but the period of greatest heat is about a month later in coming. If the Earth and the atmosphere could retain none of the heat which is showered down from the Sun, the period of greatest heat would exactly coincide with the summer solstice. However, the accumulation of heat retards the time of the greatest heat until about a month after the solstice—the end of July and beginning of August. Similarly the period of greatest cold is a month later than that of least sunlight—the end of January and the beginning of February.

Gradually summer passes into autumn. After the summer solstice is past, the Sun begins to rise later and later every morning and sets a little earlier every evening; and in addition, the orb of day does not rise so high in the heavens. This continues until the autumn equinox, when the sun rises due east and sets due west. In fact, day and night are equal all over the world, and the conditions are the same as those at the spring equinox. But there is one difference. The weather at

the spring equinox is generally cold and uncertain, while at the corresponding period in autumn it is summer-like and pleasant. This is due to the same cause which was previously mentioned, that after summer solstice the Earth continues to store up heat, while after winter the Earth is slow to absorb heat. In short, the autumn equinox generally takes place in summer-like weather. As an American astronomer expresses it: "Not until falling leaves begin to flutter about our feet, and grapes and apples ripen in orchard and vineyard, do we realise that autumn is really here—that everything is mellow and finished. Our hemisphere is turning yet farther away from that Sun on which all growth and development depend. When trees are a glory of red and yellow and russet brown, when corn stands in full shocks in fields, and day after day of warmth and sunshine follow through royal October—it seems impossible to believe that slowly and surely winter can be approaching. But soon chilly winds whistle through trees from which the bright leaves are almost gone; a thin skin of ice crystals shoots across wayside pools at evening, and speedily shivering winter is upon us. Just before Christmas this part of our Earth is tipped its farthest away from the Sun. Then for a few days the hours of darkness are at their longest. The sap has withdrawn far into the roots of the trees until the cold shall abate; leaden skies drop snowflakes, and earth sleeps under a mantle of white."

This description applies only to the temperate zones of the Earth. As we go northwards we approach the exaggerated aspects of the same phenomena—the midnight Sun and the long polar night. The cause of these phenomena is a source of difficulty to many, but it is quite easily understood with a little thought.

At midnight in the end of June, in Scotland there is very little darkness. The sky never grows actually dark. We seem to see the glow of the Sun almost up to midnight after it sinks in the north-west. As we go farther north we see more and more of the Sun. We follow it farther and farther until it just goes below the horizon, and no more. Still farther north it skirts the horizon, and is visible all night at the sixty-sixth parallel of latitude. Beyond this the Sun does not disappear at all in summer, and there are six months of daylight.

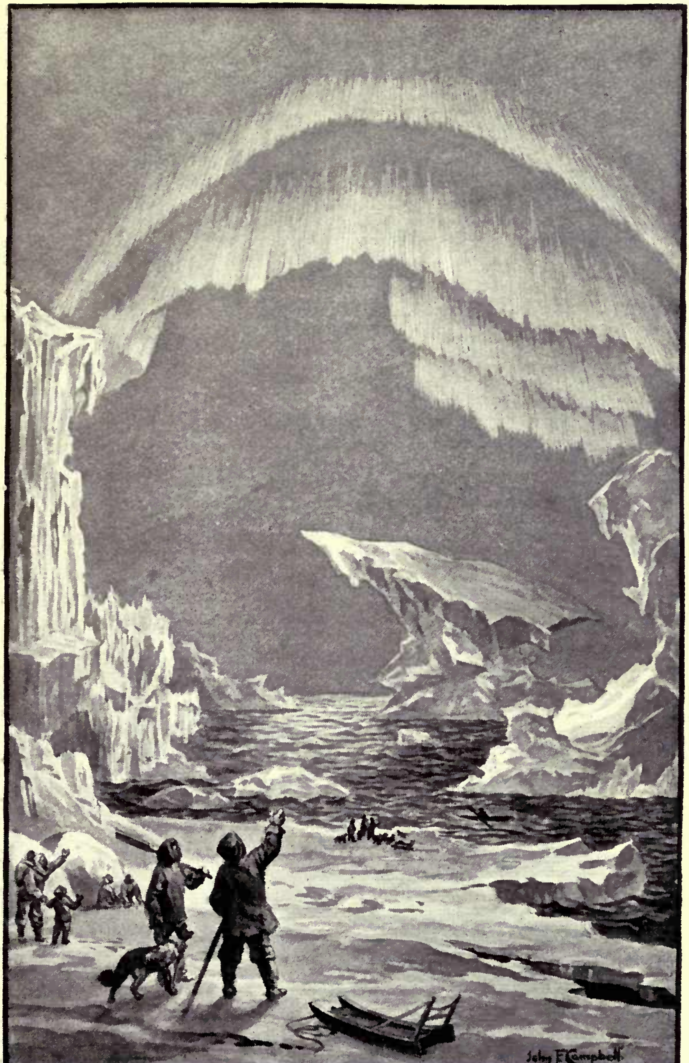
The phenomenon of the midnight Sun draws many to the northern parts of Sweden, Norway, and Russia, where for a few days at the summer solstice the sun merely skirts the northern horizon. A good description of the midnight Sun is given by Paul du Chaillu in his account of his travels in Scandinavia: "The brilliancy of the splendid orb varies in intensity, like that of sunset and sunrise, according to the state of moisture of the atmosphere. One day it will be of a deep-red colour, tingeing everything with a roseate hue and producing a drowsy effect. There are times when the changes in the colour between the sunset and the sunrise might be compared to the variations of a charcoal fire, now burning with a fierce red glow, then fading away and rekindling with greater brightness.

"There are days when the Sun has a pale, whitish appearance, and when even it can be looked at for six or seven hours before midnight. As this hour approaches, the Sun becomes less glowing, gradually changing into more brilliant shades as it dips towards the lowest point of its course. Its motion is very slow, and for quite a while it apparently follows the line of the horizon, during

which there seems to be a pause, as when the Sun reaches noon. This is midnight. For a few minutes the glow of sunset mingles with that of sunrise, and one cannot tell which prevails; but soon the light becomes slowly and gradually more brilliant, announcing the birth of another day. . . . How beautiful was the midnight. How red and gorgeous was the Sun! How drowsy was the landscape; Nature seemed asleep in the midst of sunshine; crystal dewdrops glittered like precious stones as they hung from the blades of grass, the petals of wild flowers, and the leaves of the birch trees."

Farther north the Sun is constantly visible and the north pole has six months' continuous light. But there is another side to the picture. For six months there is continuous night, and even in the north of Sweden, Norway, and Russia there are days in midwinter when the Sun does not rise, just as in summer there are days when it does not set. Du Chaillu, after describing the midnight sun, has the following remarks on the winter in the same region, which is worth quoting: "The grass turns yellow; the leaves change their colour and wither and fall; the swallows and other migrating birds fly towards the south; twilight comes once more; the stars, one by one, make their appearance, shining brightly in the pale-blue sky; the Moon shows itself again as the queen of night, and lights and cheers the long and dark days of the Scandinavian winter. The time comes at last when the Sun disappears entirely from sight; the heavens appear in a blaze of light and glory, and the stars and the Moon pale before the Aurora Borealis."

Such are the various phenomena resulting from the fact that the axis of the Earth is inclined to the plane, or level, of its orbit. Were the axis upright, there



THE AURORA BOREALIS

The aurora, which illuminates the long winter nights of the far North, is one of the most wonderful sights in the skies. Sometimes seen in our latitudes, it is seen to most advantage in the far North. Of an undoubted electrical origin, it varies in harmony with the sun-spot period about every eleven years.

would be no seasons, no spring-time, no summer, no autumn, no winter season; there would be no midnight Sun and no long polar night. In fact the continuous state of affairs would be an everlasting springtime without the charm of our earthly spring. This seems to be the state of affairs on Jupiter, where the axis is nearly perpendicular to the planet's orbit.

Another fact has also something to do with the seasons, though only in a modified degree. As the orbit of the Earth is not a perfect circle, but an ellipse, the Earth is at one point of its orbit nearer to the Sun than at the other. The Earth is nearer to the Sun by three million miles in our winter than in our summer. At first this seems a paradox, that the time of closest approach to the orb of day is the time of greatest cold. A little consideration, however, soon disposes of the difficulty. In the northern hemisphere the decreased distance of the Sun modifies the severities of winter, while its increased distance mitigates the heat of summer.

In the southern hemisphere, on the other hand, the time of greatest heat takes place when the Sun is nearest, and the time of greatest cold when the Sun is at its greatest distance. Thus the climate in the northern hemisphere is rendered more equable than that in the south.

Thus we understand that it is owing to the inclination of the axis of the Earth that the Sun's apparent path in the heavens, *the ecliptic*, is tilted, and that the Sun rises so much higher in the sky in summer than in winter. A similar line of reasoning applies to our satellite the Moon. There is much less moonlight in summer than in winter. At a first consideration it seems as if this was owing to increased daylight, the

moonlight not being required, and consequently not noticed; but such is not the case. There is really less moonlight in summer than in winter. This arises from the fact that before the Moon can be "full" and shining with complete radiance, it must be "in opposition" to the Sun, that is, situated in the diametrically opposite portion of the sky. In winter the Sun is traversing the lower zodiacal constellations, and as a result the Moon at the full phase passes through the higher. The full Moon at midwinter has the same situation as the Sun at midsummer. Thus in winter we get more moonlight than sunlight. In summer the conditions are reversed. The Sun is in the higher constellations; consequently the full Moon at midsummer occupies the place of the Sun at midwinter, and thus there is more sunlight than moonlight. Instead of shining from on high with silvery radiance, the Moon, in summer, creeps through the lower constellations, gleaming with a golden hue, which harmonises with the period of summer-time. As Mr. Maunder puts it: "The evasive Moon recognises that the season belongs by right to her more powerful brother, and timidly skirts the south as if anxious to escape notice."

The apparent yearly motion of the Sun is due to two causes—the motion of the Earth and the inclination of the Earth's axis. The apparent motion of the Sun is not itself visible, but we can trace it in an apparent drift of the stars into the sunlight. The stars, as a result of the Sun's apparent motion amongst them, set four minutes earlier each night. In a fortnight or a month this makes an appreciable difference in the aspect of the sky. For instance, at 10 P.M. in the beginning of January, Orion and the winter constellations occupy

prominent positions in the southern heavens. At the same hour a month later they have moved considerably to the west, while in March they are beginning to pass over towards the western horizon. By watching these changes with care and attention, the ancient astronomers were enabled with tolerable accuracy to trace the apparent pathway of the Sun among the stars.

A word may be said here as to the difference of the day measured by the Sun—"the solar day"—and that measured by the stars—"the sidereal day." Sidereal time is the exact time required for one star to move from the meridian round to the meridian again, in fact it is the exact time required by the Earth to rotate on its axis. But the sidereal day is not the ordinary day. Were the Earth standing still it would be so. But our planet not only whirls round on its axis; it is also moving round the Sun. As a consequence of the motion of the Earth, which gives rise to an apparent motion of the Sun, the Sun appears to come to the meridian four minutes later each day if we reckon time by the sidereal clock. In other words, the day measured by the Sun is four minutes longer than the day measured by the stars, and the difference amounts to exactly one day in each year. Now sidereal time is in reality the only true measurement of the day, because it is the exact time of the rotation of the Earth's axis. But it is impossible to measure our ordinary time by this method. Professor Todd puts it very clearly in the following words: "Sidereal noon comes at all hours of the day and night during the progress of the year. Plainly, then, sidereal time is not a fit standard for regulating the affairs of ordinary life, for while it would answer for a fortnight or so, the displacement of four

minutes daily would in six months have all the world breakfasting after sunset, staying awake all through the night, and going to bed in the middle of the forenoon." The difficulty cannot be exactly solved by taking the solar day instead of the sidereal, for, as Professor Todd says, "Begin on any day of the year and observe the Sun's transit of the meridian as you did that of a star. The instant when the sun's centre is on the meridian is known as apparent noon. If you repeat the observation every day for a year and compare the intervals between successive transits, you will find them varying in length by many seconds, because they are all apparent solar days; they will not all be equal as in the case of the star. By taking the average of all the intervals between the Sun's transit—that is, the mean of all the apparent solar days in the course of the year—an invariable standard is obtained like that from the stars themselves." Thus we have the mean solar day by which all the clocks and watches in everyday life are regulated.

CHAPTER III

THE ORB OF NIGHT

IN early times, as was seen in the previous chapter, men believed that the Earth was the centre of the Universe, and round it all the orbs of heaven revolved. To-day we know that only one celestial body owns allegiance to the Earth. That orb is our satellite, the Moon, which goes round our world once in about twenty-seven days. The Moon's revolution round the Earth from east to west in a little over a day is only apparent, the result of our planet's rotation on its axis, but its motion from west to east is real.

We owe much to the Moon. To it we owe the glorious silvery light which our satellite sheds on us. As Flammarion has said : "It is the delightful hour when all Nature pauses in the tranquil calm of the silent night. The Sun has cast his farewell beams upon the weary Earth. All sound is hushed. And soon the stars will shine out one by one on the bosom of the sombre firmament. Opposite to the sunset in the east the full Moon rises slowly, as it were, calling our thoughts towards the mysteries of Eternity, while her lamp light spreads over space like a dew from heaven." Not only is the moonlight useful, it is exquisitely beautiful.

The most casual observer of the heavens cannot fail to notice that as the Moon moves eastwards in the heavens its form changes. When we first see the new Moon in the western sky above the sunset, it is a slender crescent

of silvery light. Night after night it grows in size until about five days after we first see it it is half full. It has reached its "First Quarter." It continues to grow for about another week, until one evening it rises just as the Sun sets, and reaches the meridian, the point due south, about midnight; while it is fully illuminated and its round disc sheds over our world that inimitable light known as moonlight. Then slowly its size decreases. It rises later and later, and grows smaller and smaller, until when it reaches its "Last Quarter" it is only to be seen in the morning hours. And then it draws closer to the Sun until its thin little crescent is lost in the sunrise, to emerge some days from the sunset as "New Moon."

Those who do not give the matter sufficient consideration believe that the Moon actually changes its shape as it moves round the Earth. Indeed it is recorded of a novelist that he wrote of a star shining between the horns of the crescent Moon; the poet Coleridge makes the same mistake in the "Ancient Mariner." A little consideration, however, will show that there is no real change of shape. Like our own world, the Moon is a dark globe, and it only shines by the reflected light of the Sun. Therefore, only one half of the globe is illuminated at once. Just before the crescent of the new Moon appears, when the Moon is between the Earth and the Sun, the dark side of the Moon is turned to the Earth and we do not see it. At First Quarter we only see one half of our satellite illuminated. As the Moon moves eastward we see more and more of the illuminated surface, until at full Moon the orb is at the other side of the Earth from the Sun, and we see it fully illuminated. Then as it draws closer to the Sun we see less and less of the illuminated surface, until it becomes once again invisible.

The New Moon and the Setting Sun

THE ORB OF NIGHT

What is the distance of the Moon? That is the first question which presents itself to the beginner in astronomy. The distance varies slightly from time to time as its orbit round our Earth is not circular, but slightly elliptical or oval; but the average distance is 238,000 miles. It is near to us when compared to the other celestial bodies. But the question at once occurs, How is it possible to measure the distance? We do not require to reach the Moon in order to measure its distance, any more than we require to ascend a mountain to measure its height. In these measurements we proceed on the principles of land-surveying.

The principles of land-surveying depend on the measurement of angles. As Professor Comstock puts it: "The instruments used by astronomers for the measurement of angles are usually provided with a telescope, which may be pointed at different objects, and with a scale to measure the angle between lines drawn from the instrument to two different objects, such as two church steeples, or the Sun and Moon, and this is usually called the angle between the object. By measuring angles in this way it is possible to determine the distance to an inaccessible point."

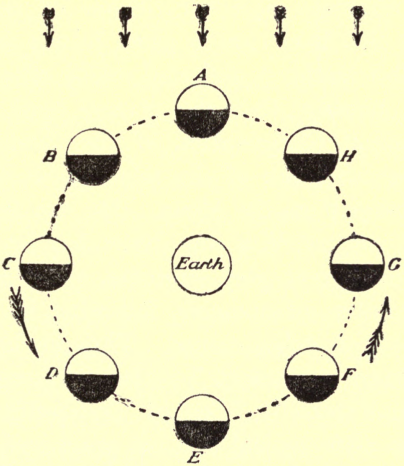
An observer wishes to measure the distance of a flagstaff at the other side of a river which he is unable to cross. Accordingly he chooses two points on his own side of the river, from which to make observations. The line joining these points he calls the base-line, the length of which he ascertains. From either point he measures the angle "subtended" by the opposite sides at these points. Having measured the angles, he now determines the elements of the triangle, and by means of trigonometry he knows the distance across the river to the flagstaff without having ever crossed it.

Similarly in regard to the distance of the Moon. One astronomer located, say, at Greenwich or Edinburgh, measures the Moon's position amid the neighbouring stars. Another at Cape Town or Sydney, measures its position seen from that place. The difference of position of the Moon at the two stations—"the parallax" as it is called—is then measured and the distance of the Moon is found to be 238,000 miles, a great distance indeed, when compared with our terrestrial standards, but very small in the eyes of the astronomer. A railway train travelling night and day at the rate of sixty miles an hour would reach the Moon in six months. The Moon, as it were, is our own particular possession. It illuminates our nights; it raises the tides in our oceans; it revolves around our world; it is the nearest of the celestial bodies, the only one whose distance is to be measured in thousands of miles. As has been remarked, it is a detached continent, and, as we shall see later, this is probably true in more senses than one. As a result of its proximity, we know more of the Moon than of any other celestial body. Indeed, we know its geography, or rather "selenography," better than we know that of the Earth. We are close enough to the Moon to see its surface spread out before us in a bird's-eye view. By trigonometrical measurements we can measure the heights of the lunar mountains. We have seen the poles of the Moon.

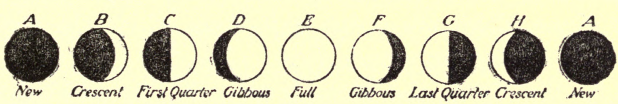
This, however, only applies to one hemisphere of the Moon. The other side has never been seen by human eye. The explanation is that the Moon, instead of turning on its axis in twenty-four hours like the Earth, requires for its rotation on its axis the exact period of its revolution. Thus the Moon always turns the same

face to the Earth. Owing, however, to the fact that the Moon's velocity in its orbit varies, the orbit being slightly elliptical, while the rate of rotation remains the same, we sometimes catch a glimpse of the other

Direction from which the Sun's rays are coming.



Various positions and illumination of the Moon by the Sun during her revolution around the Earth.



The corresponding positions as viewed from the Earth, showing the consequent phases.

FIG. 1.—Orbit and Phases of the Moon.

hemisphere. This is known as the "libration" of the Moon.

So far, the Moon has been viewed as an object and as the satellite of the Earth. It must now be considered as a world. When we look at the Moon, even casually,

we cannot but notice that the bright disc is diversified. Most people see in the full Moon a likeness to a human face, and this is called "the Man in the Moon." Even in the crescent Moon and half Moon it is obvious that there are dark markings. In early times no one knew what these markings signified. Some of the ancients thought that the Moon was a great mirror in which we saw the Earth's markings reflected, while others held the correct view, namely, that the diverse markings represented the actual configuration of the Moon's surface. Soon after the invention of the telescope, Galileo turned his little instrument on the Moon. He was thus enabled to show that our satellite was diversified by mountains and valleys, and great grey stretches, which he believed to be seas. Later astronomers, following in this belief, gave these grey stretches names. Thus we have on the Moon the "Mare Serenitatis"—"Sea of Serenity"; the "Mare Tranquillitatis"—"Sea of Tranquillity" &c. It was obvious as astronomical research progressed that these stretches were not seas, but great plains. It is now known that there are no seas on the Moon, but the old names are retained for convenience. It is quite possible that these plains are ocean beds, from which the water has long since disappeared.

Like the Earth, the Moon is diversified by all kinds of formations. There are mountain ranges, isolated mountains, and volcanic craters. The mountain ranges have been called after mountains on the Earth. Thus there are on the Moon, the Alps, the Apennines, and the Carpathians. The highest mountains on its surface, so far as known, are the Doerfel and Leibnitz mountains, about 25,264 feet high. As Flammarion remarks: "Relatively to its proportions, the satellite is much more

mountainous than the planet, and the mountainous giants are much more numerous than here. If we have peaks like the highest of the Himalayas, and of the whole Earth, whose elevation of 29,000 feet is equivalent to $\frac{1}{1140}$ the diameter of our globe, there are peaks on the Moon of 25,264 feet, those of Doerfel and Leibnitz, the height of which is equivalent to $\frac{1}{470}$ the lunar diameter." It will thus be seen that the peaks of the Moon are much higher in proportion to its size than those of our own world. The surface, too, is much more rugged and mountainous than that of the Earth. There has been much volcanic activity on the Earth, but there has been much more on the Moon. Indeed on it the volcanic crater is the commonest type of formation. The smallest telescope will reveal the largest of these wonderful formations. The craters are named after eminent astronomers, men of science, and philosophers, and among the more prominent are Tycho, Copernicus, Plato, and Archimedes. Some of these craters are enormous. A large type of formations somewhat similar to the craters are the walled plains. Some of these are actually 150 miles across; and they are, as their name implies, encircled by ramparts of considerable breadth, which in some cases rise to a height of about 12,000 feet above the enclosed plains. In some cases, too, the floors of these walled plains are diversified by the presence of minute craters and mountains.

Another curious formation peculiar to the Moon is that known as the "rills." Of these rills the late Mr. Elger, a well-known English observer of the Moon, writes: "They often extend for hundreds of miles in approximately straight lines over portions of the Moon's surface, frequently traversing in their course ridges,

craters, and even more formidable obstacles, without any apparent check or interruption. Their length ranges from ten or twelve to three hundred miles or more, their breadth from less than half a mile to more than two, and their depth from a hundred to four hundred yards." On the Earth we have nothing like them—great yawning chasms running for miles over craters, mountains, and plains.

The study of the Moon's surface is now a distinct branch of astronomy. To it many distinguished astronomers, such as Mädler and Schmidt, have given the best part of their lives. Schmidt, a notable German astronomer, commenced his observations of the Moon, with a view to constructing a chart, at the age of fourteen. He just lived to finish his great work, about forty years later. In recent years photography has been largely used in the study of the Moon, and in the able hands of Professor W. H. Pickering of Harvard, U.S.A., much has been learned in this way concerning the lunar surface. To the casual observer the first quarter is the most satisfactory phase. The full Moon is a disappointing object in the telescope. The Sun is shining direct on its surface; it is noon on the part of our satellite which we are observing, and the mountains and crater walls cast no shadows, just as on our own world the shadows are shortest at noon. At the first quarter, on the other hand, it is positively fascinating to watch the dividing line between light and darkness—the terminator, as it is called in astronomical language—and to note the sunrise on the various mountain peaks. It is about the time of the first quarter that we see the surface of the Moon at its best. It is at this time that the Moon is most useful to the astronomer, just as the full phase

From a photograph taken at the Paris Observatory by M. P. Puiseux

THE MOON

This is a photograph taken near the first quarter, but, of course, inverted, as in astronomical telescopes. The craters and mountain ranges are well shown.

is the most useful to the ordinary inhabitant of the Earth.

We have briefly described the surface of the Moon—its grey plains, its mountains, its craters, and rills. What do we learn from a study of these features? Is our satellite a world like the Earth?

It is not a world like the Earth. The first great difference is obvious to the most casual observer. The Moon's surface is always to be seen clearly defined without a trace of haziness. There is no atmosphere. Practically it is an airless globe. Could we see the Earth from some point in space we should sometimes see it clearly defined when the atmosphere was clear, but at times we should see it enshrouded in cloud. But we never see clouds on the Moon; it is airless. Not only is there no air. There is no water. The Moon's surface is, to all intents and purposes, changeless, airless, and lifeless. Without air there can be no water, without water, no life. There is no vegetation on the grey plains, no heathery moors, no pine-covered mountains, merely a succession of arid, it may be crumbling rocks. As Professor W. H. Pickering has pointed out, there is probably a certain amount of change, almost imperceptible. At the bottoms of the craters there seem to be some last relics of the Moon's atmosphere, and perhaps the remnants of a lunar vegetation, perhaps a feeble little eruption almost unnoticeable, but that is all. The Moon is a dead world, and it is exceedingly unlikely—indeed we may say it is impossible—that any but the very lowest forms of fungus-life could live on it for one hour. The want of air, as already said, means want of water; it also means violent change of temperature. The Moon's day is equal to twenty-nine and a half of our days in length. For half of this

period the Sun beats down on the surface of the Moon. There is nothing to temper the broiling heat. The surface is scorched and baked. Then the Sun sets, and the long night comes on. There is no air to retain the heat; it escapes into space, and the lunar surface is frozen by an intense cold, a cold more terrible than we can conceive.

Could we visit the Moon, what an extraordinary world we should find it to be! There is no atmosphere, and as a consequence of this the stars are visible in all their glory when the Sun is shining. On Earth the stars are invisible in the daytime because the sunbeams are dispersed in our atmosphere, and this "veil of sunbeams" hides the stars from view. But on the Moon there is no veil of sunbeams. The Sun is seen with all his appendages which on Earth are invisible except during total eclipses —his red flames and his corona. Slowly, very slowly, the Sun creeps across the black sky, until in fourteen earthly days he sinks below the horizon to illuminate the opposite hemisphere.

From the side of the Moon facing earthwards, there is seen hanging, fixed and motionless in the sky, an enormous orb, a gigantic moon shedding its rays continually on the surface of our satellite. Sun and stars may pass behind it, but this orb hangs fixed in its place in the heavens. This body, which appears from thirteen to fourteen times as large as the Moon seems to us, is our dwelling-place, the Earth. The magnificence of the "Earthlight" which our world sheds on the surface of the Moon, is difficult to imagine. From the Moon's surface our world is to be seen in all its aspects—blue skies, clouded skies, haze, and mist. Sometimes it is "full Earth," sometimes "new Earth," sometimes the quarters, continually spinning on its axis, and exhibiting

every part of its surface in turn. Of the power of this reflected light we may get an idea from a consideration of a common phenomenon seen from the Earth. Most people have seen the "old Moon in the new Moon's arms"—the crescent Moon completed by a darker portion which shines with a dull light. This is the portion of our satellite illuminated by earthshine and reflecting back to us the light of our own planet. Thus we see the light of our own world reflected back to us from the heavens.

The chief features of the silver orb of night have been described. It has been seen to be a globe, similar in some respects to the Earth, but vastly different in its physical condition — a globe uninhabited and uninhabitable, a succession of rugged, jagged rocks, great grey barren plains, and volcanic regions. We have now completed our survey of the Earth's vicinity, and have passed the first sign-post on a journey through the depths of space.

CHAPTER IV

THE FOUNTAIN OF LIGHT

SCHIAPARELLI has called the Sun "the most magnificent work of the Almighty," and so far as our world is concerned the orb of day certainly merits the title. Without the Sun, life on the Earth would be impossible; without the Sun, indeed, there would be no Earth. Yet, so accustomed are Earth's inhabitants to the day star, that day after day we experience light and heat, year after year we enjoy the summer season, and do not stop to consider the source of these marvels. It is well to remember, occasionally at least, that the Sun is all in all to our planet.

There are many marvels in connection with the Sun, but perhaps nothing is more astounding than its vast distance and enormous size. The distance of the Sun from the Earth, as ascertained by methods similar to those used to measure the distance of the Moon—mentioned in the previous chapter—is, roughly speaking, ninety-three millions of miles. The Earth's orbit is not exactly circular, it is slightly elliptical, and as a result the Sun's distance varies from ninety-one to ninety-four millions of miles. It is easy to write out the figures representing ninety-three millions of miles (93,000,000), but it is not so easy to realise the enormous distance which these figures represent. Sir Robert Ball has given an excellent illustration as follows: "How long will the

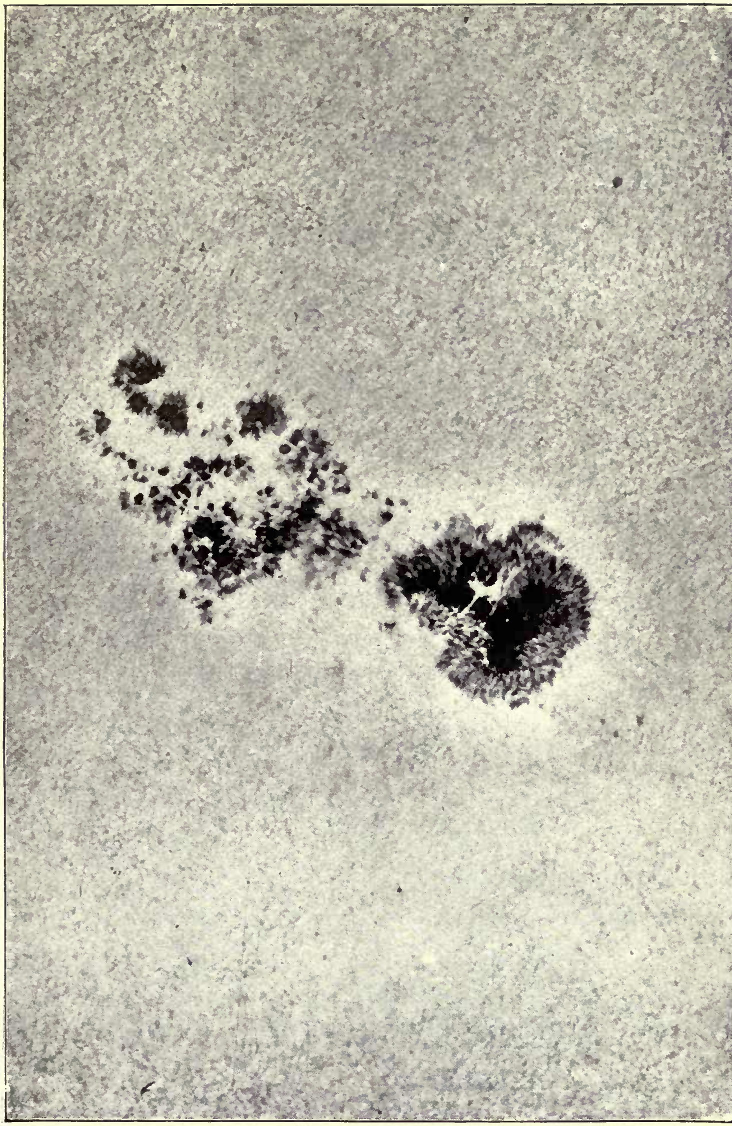
clock have to tick before it has made as many ticks as there are miles between the Earth and the Sun? Every minute the clock, of course, makes sixty ticks, and in twenty-four hours the total number will reach 86,400. By dividing this into 93,000,000 you will find that more than 1076 days, or nearly three years, will be required for the clock to perform the task."

There is another vivid way of illustrating the Sun's distance. A tour round the world, involving a journey of 24,000 miles, can be accomplished in sixty days. Before a traveller could cover 93,000,000 miles he would require to accomplish about 4000 of these journeys. He would be six hundred years old when he arrived, even supposing him to start on his journey as an infant. Take another illustration. If it were possible to travel to the Sun in a railway train, night and day without stopping, at the uniform rate of forty miles an hour, it would require no less than 265 years to reach its destination. If the train had started in the time of Cromwell, it would not yet have reached its destination.

No less astounding than the Sun's distance is its size. The diameter of the solar globe is 866,000 miles. No fewer than 109 globes of the size of the Earth would be necessary to stretch from the one side of the Sun to the other. Properly to estimate its size in comparison with that of the Earth, we must consider its volume. The volume of the Sun is one and a quarter millions of times greater than the volume of the Earth. If all the planets, satellites, and cometary and meteoric bodies in the solar system were rolled into one globe, it would take no fewer than 750 of such globes to equal the volume of the Sun. Professor Gregory gives the following unique illustration of the Sun's size: "If we had a contract

to build up this stupendous bulk, and were to deliver a load of the same size as the Earth every hour, the order could be completed working night and day for 150 years."

We have seen by how much the Sun exceeds the Earth in volume. In weight, however, the Sun exceeds our world only 330,000 times. This proves that the density of our world is about four times that of the Sun. The reason of this is that while our world is a solid globe, the Sun, as we all know, is a great ball of gas, incandescent, glowing with an inconceivable heat. We all feel that the Sun is very hot ; even on our planet it sometimes shines so brightly as to make us uncomfortable. What, then, must be its actual heat if it can be oppressive at a distance of 93,000,000 miles ? Perhaps the best illustration on this point was given by Professor Young, the well-known American astronomer : "If we could build up a solid column of ice from the Earth to the Sun two miles and a quarter in diameter, spanning the inconceivable abyss of 93,000,000 miles, and if the Sun should concentrate his power upon it, it would dissolve and melt, not in an hour, not in a minute, but in a single second ; one swing of the pendulum and it would be water, seven more and it would be dissipated in vapour." The estimated temperature of the solar surface is no less than 18,000 degrees Fahrenheit. The heat emitted by the Sun in each second, according to one of the most distinguished of modern astronomers, is equal to that which would result from the combustion of eleven quadrillions, six hundred thousand millions of tons of coal burning at the same time. This does not help us to realise the heat of the Sun. It helps us rather to realise how far the whole subject transcends our comprehension. How is this enormous heat maintained ? It has been calculated



Photograph of a Sunspot

This fine picture was taken by the late M. Janssen. The granular structure of the Sun's surface is here well represented. (From *Knowledge*.)

that if the Sun were composed of coal it would burn out in six thousand years. But the orb of day has lasted much longer, and seems to be in its prime. The most probable explanation of the source of the Sun's heat is that the solar globe is contracting. This contraction generates heat, which it has been calculated will keep the Sun at a high temperature for ten million years! It is also possible that the element radium may have something to do with the maintenance of the solar heat, but here we are in the region of speculation.

Equally astounding is the brightness of the Sun. The "intensity of sunlight," as it is called, at the surface has been estimated at 190,000 times that of a candle flame, 146 times that of a calcium light, and three and two-fifths that of an electric arc. Then in regard to the brightness of the sun, it is estimated that the total light is equal to 1,575,000,000,000,000,000,000 millions of wax candles. This unthinkable row of figures can assist us in realising, as it were, the incomprehensibleness of the brilliance of the day star. In reference to the light and heat of the Sun, it is well to bear in mind that the Earth and its inhabitants receive only a very small portion. It has been calculated that if the Sun were expending, instead of energy, money at the rate of £18,000,000,000 a year, the earth's annuity would be only £9.

Owing to the dazzling brightness of the Sun, it is impossible to observe it in a telescope without the aid of a dark glass. When we first observe the Sun through the telescope, we behold a disc of yellow light. If we scan the disc carefully we shall, in all probability, notice one or two minute markings. These are the sunspots. These spots are not permanent

features of the Sun, like the mountains and craters of the Moon. They are merely temporary markings. Sometimes, indeed, they disappear in a day. An astronomer looks at a sunspot carefully one day, and makes a drawing of it. Next day he looks for it again, and finds that it has vanished or completely changed its form.

Now what are these sunspots? They were a mystery to the early astronomers who first discovered them—Galileo and Scheiner. Indeed, the discovery of these spots came on the men of science of the day with a shock of surprise. It was thought that the Sun was too "pure" to have "defects" on its surface, and accordingly the astronomers who first announced that they had seen spots on the Sun, were openly disbelieved. However, the spots were soon proved beyond all doubt to be really features of the disc of the Sun. Observation with moderate-sized telescopes, and even with small instruments, reveals a very remarkable fact concerning these spots; they are rents in the glowing atmosphere of the Sun. Another remarkable fact concerning sunspots is that they are not uniformly dark. The black central portion—the umbra, as it is called—is surrounded by a grey portion—the penumbra. These are supposed to be not really black and grey, but merely dark in comparison with the brilliant envelope of the Sun—the "photosphere," or "light-sphere," as it is called. Spots are supposed to be vast cavities in the glowing envelope. They vary greatly as to size. Sometimes a spot is so large as to be visible to the unaided eye. One famous spot was seen in February 1892. Its length was no less than 92,000 miles, and its breadth was 62,000 miles. A number of small spots were connected with the large one,

and the length of the group was 162,000 miles, the breadth being 75,000 miles. The spot group had an area of 3500 million square miles. Seventy bodies equal in size to the Earth would have been required to cover up this gap in the photosphere. Most spots, however, are by no means so gigantic as was this particular example.

Sunspots reveal to astronomers many important facts. They show that the Sun, like the Earth, rotates on its axis. By observations of the displacements of many spots, astronomers have found that the rotation of the Sun is performed in twenty-five days at the equator, and twenty-seven and a half days at forty-five degrees north and south of the equator. That is to say, the Sun does not rotate as a whole. Different parts have different periods. The "day" of the Sun therefore is over twenty-five times longer than that of our planet.

Another remarkable fact which sunspots reveal concerns their own distribution. At some seasons spots are much more numerous than at others, and it has been ascertained that they increase and decrease in about every eleven years. Thus 1889 and 1901 were years of few sunspots, while 1893 and 1905 were years of many spots. The history of the discovery of the "solar cycle," as this increase and decrease is called, is one of the most interesting in the annals of astronomy. In 1826 a German apothecary named Schwabe, who was interested in the study of astronomy, commenced to count the number of spots on the Sun from day to day. His only instrument was a small hand telescope. After about twenty years he found traces of the increase and decrease, and by 1851 had fully proved the existence of the "sunspot period." Here was a discovery which had escaped all the great

astronomers, and fell to be made by an amateur. Besides the spots, the telescope reveals the existence of bright ridges which are known as "faculæ." These are usually observed close to the spots. Like them, they are far from being permanent features. Even in a few hours they utterly change their shape, and in some cases it is impossible to sketch their form, so quickly do they alter and disappear. Although they are closely connected with spots, there is one remarkable difference. Spots are usually confined to two zones above and below the solar equator, while faculæ are found in every latitude, except in the polar regions.

It is important to remember that the greater part of our knowledge of the Sun has been derived from observations not with the telescope alone, but with the telescope aided by an instrument even more remarkable. This instrument is called the spectroscope, and in order to understand properly many of the latest and most wonderful discoveries in astronomy, it is necessary to have some idea of the principle of this instrument. Put briefly, it may be said that while the telescope reveals the celestial bodies, the spectroscope tells us the materials of which they are composed. Just as water can be broken up into its elements, oxygen and hydrogen, sunlight can be broken up into its primary colours, red, orange, yellow, green, blue, indigo, and violet. This can be done by passing sunlight through a prism of glass, and the strip of rainbow-coloured light which results is called the solar spectrum. In fact the rainbow is merely the solar spectrum produced naturally by what is known as refraction, the bending or deflection of the rays of the Sun. The solar spectrum was first investigated by Sir Isaac Newton, but it was not until the year 1814 that

Fraunhofer, a German astronomer, noticed in the spectrum a number of dark lines. He detected about three or four hundred of these, and named the more prominent by the letters of the alphabet from A in the red to H in the violet. He was greatly perplexed at first over the meaning of the lines. He found that they were conspicuous in the spectra shown by the Moon and planets, but not in the spectra of all the stars. In other words, the lines were found to be characteristic of sunlight, whether direct or reflected, and sunlight only. It is possible, however, to analyse other kinds of light besides sunlight. In a physical laboratory the lights of heated elements may be observed with the spectroscope, an elaborated form of the ordinary prism, and when each element is thus analysed it is found to be characterised by one or more bright lines. In 1859, Kirchhoff, a German scientist, showed that while a gaseous substance gives a spectrum of bright lines, a luminous solid, or liquid, gives a continuous spectrum. In the words of a lucid astronomical writer, "substances of every kind are opaque to the precise rays which they emit. That is to say, they stop the kinds of light or heat which they are then actually in a condition to radiate." This was the solution of the problem. All that astronomers had to do was to examine the spectra of heated elements and fix the position of the bright lines in these spectra, and afterwards compare the position of these lines with the position of the dark lines in the spectrum of the Sun. As the positions were in many cases identical, it became possible to ascertain of what substances the Sun was composed, and Kirchhoff was enabled to detect the presence in the orb of day of such well-known elements as sodium, iron, copper, zinc, and magnesium.

One of the uses of the spectroscope is to determine the elements of the Sun; but it has other uses. It has disclosed to astronomers the existence of another atmosphere. In the chapter on eclipses of the Sun, mention will be made of two solar features which are then seen to full advantage. These are the red flames or prominences, and the corona, a halo of silvery light. We do not see these features of the Sun every day, because they are obscured by its dazzling luminosity. When, however, the dark globe of the Moon interposes and cuts off the light of the photosphere, they are visible. By means of the spectroscope it is possible, however, to observe the prominences daily, and consequently our knowledge of these marvellous objects has greatly increased since the application to them of this instrument. They have been ascertained to be tongues of glowing hydrogen shot forth with tremendous power from the chromosphere, a thin layer surrounding the photosphere. Some of these prominences are enormous in height. An extraordinary outburst was witnessed on September 7, 1871, by the late Professor Young, one of the foremost solar observers. At noon he was examining a prominence by the spectroscope method. "It had remained unchanged since noon of the day previously—a long, low, quiet-looking cloud, not very dense, or brilliant, or in any way remarkable except for its size." At 12.30 A.M. the Professor left the spectroscope for a short time, and on returning half-an-hour later to his observations, he was astonished to find the gigantic Sun flame shattered to pieces. The solar atmosphere "was filled with flying *débris*," and some of these portions reached a height of 100,000 miles above the solar surface. Moving with a velocity which, even at the distance of 93,000,000 miles, was almost perceptible

to the eye, these fragments doubled their height in ten minutes. On January 30, 1885, another distinguished solar observer, the late Professor Tacchini of Rome, observed one of the greatest prominences ever seen by man. Its height was no less than 142,000 miles—eighteen times the diameter of the Earth. Another mighty flame was so vast that supposing the eight large planets of the solar system ranged one on the top of the other, the prominence would still tower above them.

Like the spots, the prominences increase and decrease every eleven years. The law which governs the number and distribution of the spots also governs the prominences. This eleven-year period governs more than prominences and spots. It also governs the shape of the corona, a silvery radiance which envelops the Sun outside of the chromosphere. The entire Sun is governed by this period, which as a result influences the other bodies of the solar system. Take the magnetic variations on the Earth. These magnetic variations indicate a period of almost eleven years. Not only the periods agree, but a great outburst of spots and prominences on the Sun is usually answered by a magnetic outbreak on the Earth. In February, 1892, a large group of sunspots appeared, and the result was great disturbances of the delicate magnetic needles kept at Greenwich and elsewhere. In February, 1907, another great group appeared. It was followed by a magnificent display of the Aurora Borealis, or Northern Lights, an electrical phenomenon which is caused by electrical discharges in the upper regions of the Earth's atmosphere. As Professor Gregory remarks: "Magnetic storms are generally accompanied by auroral displays, and *vice versa.* What is more, the frequency of auroras keeps time with the frequency of sunspots, and

therefore with the intensity and magnitude of magnetic variations." In a word, the Sun is the pulse of the solar system, from which all influences run outward.

We may now briefly review what is known of the constitution of the Sun. The central portion of the mighty orb below the photosphere has never been seen. In the words of an able writer, "Of the heat in the Sun's interior we can form no conception. The pressure within the Sun is equally inconceivable. A cannon ball weighing 100 lb. on Earth would weigh 2700 on the Sun. Thus a mighty conflict goes on unceasingly between imprisoned and expanding gases and vapours struggling to burst out, and massive pressures holding them down."

The first solar envelope is the photosphere, that bright calm-looking solar surface on which the spots appear and from which we derive our light. Above this are envelopes technically known as "the reversing layer" and the chromosphere. This latter envelope, from which the prominences emanate, may be described as a sea of fire, in a state of everlasting turmoil and unthinkable heat. Like the sea, it is restless and agitated, but its waves are waves of glowing hydrogen, and its spray fragments of shattered sun-flames. Beyond the chromosphere is the corona, a soft silvery radiance, which can only be seen when the Sun is totally eclipsed. The corona has long proved a problem to astronomers. Its shape varies in sympathy with the eleven-year period, and it seems closely connected with electricity and magnetism. It streams out from the Sun for millions of miles, becoming more and more rarefied until it gradually fades into the ether of space. It is the final solar envelope, calm and peaceful, a fitting crown for the orb of day.

This, then, is the Sun—ruler and centre of the Solar

System, to which we on Earth owe our light, heat, life. We cannot hope to realise fully the marvels of this mighty orb, or properly to appreciate the delicate mechanism, the marvellous contrivances which keep the grand central orb in touch with the little planets which circle round it. Without the Sun, not only would life on this planet be impossible, but our planet itself would not be in existence. In view of all this we can fully appreciate the remark of Proctor: "If there is any object which men can properly take as an emblem of the power and goodness of Almighty God, it is the Sun."

CHAPTER V

THE SUN'S FAMILY OF WORLDS

A STUDY of the globe of the Sun itself gives us an inadequate idea of the solar power. We cannot realise the extent of the Sun's influence until we comprehend the marvellous system of planets and satellites, asteroids, comets, and meteors which revolve round it. The Sun, as has been well said, "maintains in his rays the whole of his system. If the comparison were not offensive to the Sun-god, we might say that he is like a spider at the centre of his web. In the net of his attraction the worlds are sustained. Relatively to his magnitude and might, the planets are but toys spinning round him."

The planets are divided into three well-defined groups. Comparatively close to the orb of day, at mean distances ranging from 36 to 141 millions of miles, revolve the inner planets, consisting of four worlds—Mercury, Venus, the Earth, and Mars. Beyond the orbit of Mars we have another group, or rather ring, of seven hundred small worlds, the asteroids, planetoids, or minor planets. The largest of these is only five hundred miles in diameter. Beyond this, at mean distances ranging from 482 to 2789 millions of miles, we have the group known as the outer planets—Jupiter, Saturn, Uranus, and Neptune. Mere figures convey little or no idea of the relative distances of the planets. We may, however, represent the sizes and distances of the planets in imagination on a much smaller scale.

THE SUN'S FAMILY OF WORLDS

If we take a nine-foot globe to represent the Sun, we may represent Mercury by a large pea at a distance of 127 yards; Venus by a one-inch ball at 235 yards; the Earth by a one-inch ball at 325 yards; Mars by a half-inch marble at 495 yards, the asteroids by 700 small seeds at distances of from 676 to 1385 yards. Jupiter will be represented by an eleven-inch globe a mile away; Saturn by a nine-inch globe $1\frac{3}{4}$ miles away; Uranus by a four-inch globe $5\frac{1}{2}$ miles away. On this same scale we can represent the Moon as a pea moving in a circle at a distance of 30 inches from the ball, one inch in diameter, which represents the Earth. The actual diameters of the planets may be tabulated as follows:—

Inner planets.—	Mercury	. . . .	3030 miles
,, ,,	Venus	. . . .	7700 ,,
,, ,,	The Earth	. . . .	7918 ,,
,, ,,	Mars	. . . .	4230 ,,
The Asteroids.—	From 500 to 10 miles		
Outer planets.—	Jupiter	. . . .	92,164 miles
,, ,,	Saturn	. . . .	74,000 ,,
,, ,,	Uranus	. . . .	31,000 ,,
,, ,,	Neptune	. . . .	34,000 ,,

From this table we see that the outer planets greatly exceed in size the inner planets, which in their turn dwarf to complete insignificance the asteroids or minor planets. The three groups, in fact, are completely different in distance, size, and physical condition.

Besides the planets, another class of bodies fall to be mentioned. The planets themselves, which revolve directly round the sun, are called primary planets. But most of the planets are themselves centres of little families of moons or satellites which revolve round them and are carried along with them round the Sun. These are called secondary planets, or, more usually, satellites. Mercury

and Venus have no satellites, and only two of the inner planets are attended by moons. We all know the Moon, the Earth's sole satellite world. Mars has two satellites, but they are very much smaller than the Moon. The asteroids, of course, have no satellites, because they are much smaller than satellites themselves. But the outer planets have imposing retinues of attendants. Jupiter boasts of no fewer than eight, four large and four small. Saturn is attended by ten worlds, and in addition has a ring of meteoric particles somewhat analogous to the zone of asteroids moving round the Sun. Uranus has four satellites, and Neptune, so far as we know at present, one. These satellites vary greatly in size, from Titan, one of the satellites of Saturn, which exceeds the planet Mercury in size, to the little satellites of Mars, which are certainly under thirty miles in diameter. The orbits or pathways of the various planets round the Sun lie almost in the same plane or level, with the exception of the orbits of some of the asteroids. Along these orbits the planets travel with different velocities.

Mercury	29	miles	per	second
Venus	21	,,	,,	,,
The Earth	18	,,	,,	,,
Mars	15	,,	,,	,,
Jupiter	8	,,	,,	,,
Saturn	6	,,	,,	,,
Uranus	4	,,	,,	,,
Neptune	3	,,	,,	,,

FIG. 2.—Comparative Velocities of the Planets.

Mercury, the nearest planet to the Sun, is subjected most to the Sun's attraction, and consequently travels fastest. Its velocity is twenty-nine miles per second, or 2,505,000 miles per day. Venus travels at over twenty-one miles per second, or 1,873,000 miles per day. The velocity of

our own planet is eighteen miles per second, or 1,555,000 miles per day. Mars travels at almost fifteen miles per second, which is equivalent to 1,287,000 miles a day.

The outer planets are more leisurely. Jupiter glides along at eight miles a second, or 771,000 miles a day. Saturn's velocity is over six miles per second, which is equivalent to 536,000 miles a day. Uranus travels at a little over four miles a second, and in one day covers 372,000 miles, while Neptune, the most distant known world, moves at the comparatively slow pace of three miles a second, or 268,000 miles a day. Comparatively slow in comparison with the other planets, but absolutely very fast, Neptune rushes along in its orbit with an almost inconceivable velocity. And if Neptune's speed is so great that it cannot be realised, it is almost impossible to conceive that our world, which seems to us so still and immovable, carries us along with it in its journey through space at the rate of eighteen miles per second and Mercury at twenty-nine miles per second. The following words of Flammarion bring out this clearly: "A ball fired from a cannon leaves the mouth with a velocity of 1312 feet per second, the terrestrial globe flies 75 times quicker, Mercury 117 times faster. This is a rapidity so stupendous that if two planets were to meet in their course the shock would be frightful; not only would they be shattered in pieces, both reduced to powder, but further, their motion being transformed into heat they would be suddenly raised to such a degree of temperature that they would disappear in vapour—everything, earth, stones, water, plants, inhabitants—and they would form an immense nebula." Fortunately we need have no apprehension of such a disaster. The planets are all moving in the same direction and they are at enormous distances from one

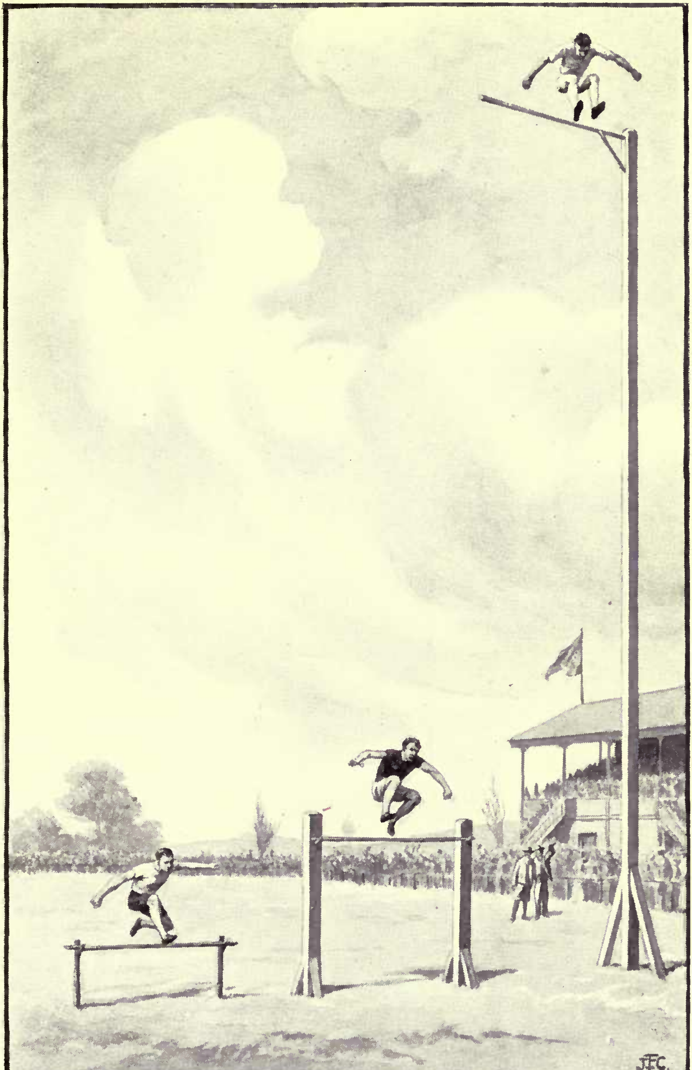
another. When Mars and the Earth are at their nearest approach, over thirty millions of miles separate them, while Venus, the nearest of all the large planets, is distant from us at its times of closest approach over twenty millions of miles.

As a result of these different speeds and different distances from the central orb of the various planets, the various bodies of the solar system require different times to perform their revolution round the Sun. Not only is Mercury closer to the Sun than is our own planet, and has therefore a smaller ellipse to traverse; it goes much more rapidly round its orbit, and therefore requires a much shorter period to perform a complete revolution.

The times of revolution of the various planets round the Sun may be tabulated thus:—

Mercury	88	days	
Venus	225	,,	
The Earth . . .	365	,,	
Mars	687	,,	
Jupiter	4332	,,	(almost 12 years)
Saturn	10,759	,,	(almost 30 years)
Uranus	30,687	,,	(about 84 years)
Neptune	60,127	,,	(about 165 years)

Just as the Earth's year is its period of revolution round the Sun, the year of Mercury is only 88 days, while that of Neptune is 60,127 of our terrestrial days, or almost 165 of our own terrestrial years. Thus, a being who had lived only twenty-four terrestrial years would be a centenarian on Mercury, while a man of eighty-four on our planet would be an infant of one year according to the length of years on the planet Uranus. In the Solar System, therefore, measurement of time is relative and depends on the distances of the various planets from the Sun.



THE VARYING FORCE OF GRAVITY ON THE DIFFERENT PLANETS

An athlete on the Moon could jump, with the same exertion, six times as high as on the Earth; on Jupiter he could only jump $\frac{1}{2.65}$ times as high. In the centre is a normal jump on the Earth; to the right a jump on the Moon; to the left a

As the different planets vary in distance, velocity, and size, they also differ in weight. Professor Gregory gives the weight of the Earth as 6000 millions of millions of tons. If we represent this by one pound, the weight of the Sun would be 150 tons; the weight of Jupiter would be 310 pounds; of Saturn 93 pounds; of Neptune 17 pounds; and of Uranus 14 pounds. The smaller planets, however, would be on the same scale, lighter than the Earth. Venus would weigh 13 ounces, Mars $1\frac{1}{2}$ ounces, Mercury 1 ounce, and the Moon about 3 drams. Although the outer planets are much heavier than the Earth, they are not so much heavier as they are larger, which shows that their density is less than that of the Earth.

On the Earth a falling body during the first second of its descent, falls through 16 feet. The following are the distances through which a similar body would fall on the other bodies of the solar system in the same time:—

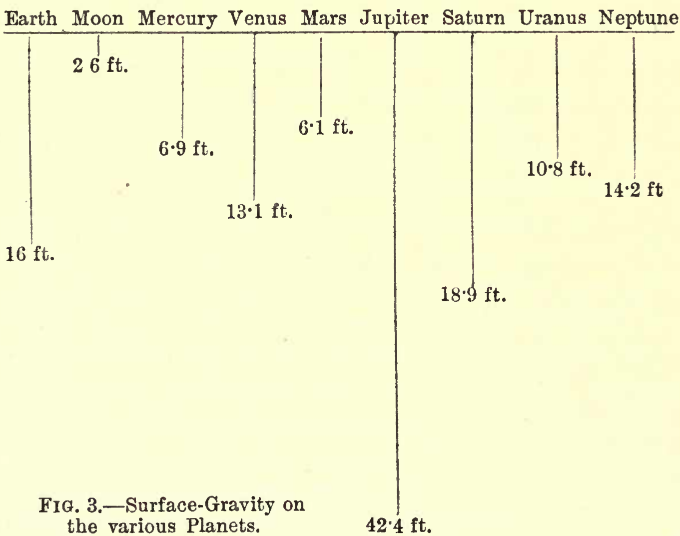


FIG. 3.—Surface-Gravity on the various Planets.

On the same scale the distance fallen on the Sun is too large to be shown—442·4 feet.

The weight of the body at the Earth's surface is the force with which the Earth attracts that body and depends on the mass of the Earth. Therefore, as the planets have different masses, a body if weighed on the different planets would have different weights. Take the case of a man who weighs twelve stones on the Earth. On the Sun he would weigh two tons. As Sir Robert Ball puts it, if a man were to be transferred to a globe as massive as the Sun, everything would weigh twenty-seven times as much as it does on the Earth. "To pull out your watch would be to hoist a weight of about five or six pounds out of your pocket. Indeed I do not see how you could draw out your watch, for even to raise your arm would be impossible—it would feel heavier by far than if it were made of solid lead. It is, perhaps, conceivable that you might stand upright for a moment, particularly if you had a wall to lean up against, but of this I feel certain that if you once got down to the ground, it would be utterly out of your power to rise again." Thus, a man living on such a globe would be unable to rise out of his bed in the morning.

A man weighing 12 stone on our world would weigh 28 stone on Jupiter, 14 stone on Saturn, 10 stone on Neptune, Uranus, and Venus. On Mars and Mercury the weight would be reduced to 5 stone, on the Moon to 2, while on the asteroids it would come down to a few ounces. Let us suppose a man of 12 stone placed on the Moon. He would be amazed to find everything one-sixth as heavy as on the Earth. His own weight would be so diminished that he could jump over a house with as little effort as he could on Earth leap across a wayside ditch.

Pulling out his watch he would feel practically no weight at all. A horseman who on Earth would consider a five-barred gate a good jump, would on the Moon leap over a hayrick with the same amount of exertion. Suppose a man were playing cricket on the Moon. On Earth 100 yards is a very good throw; on the Moon one of 600 yards would be accomplished with the same amount of exertion. One able astronomer puts this lessened gravity very clearly:—"Football would show a striking development in lunar play; a good kick would not only send the ball over the cross-bar, but it would go soaring over the houses and perhaps drop in the next parish."

If our imaginary man of twelve stones weight were transferred to one of the asteroids which circulate between Mars and Jupiter, his weight would be reduced to a few ounces. Suppose he kicked a ball into the air as an ordinary player would do on Earth, it would not, as in the Moon, go soaring over the houses; it would go soaring into space and leave the planet for ever. The force of gravity on the little asteroid would not be sufficient to counteract the upward motion of the ball, which would rush into space on a career of its own, and become a little asteroid on its own account. These illustrations bring home clearly the different masses of the various planets composing the solar system.

For reasons which will be explained later, the planets have different densities. Thus Mercury is in proportion to its size a very heavy planet. Its density is equal to that of zinc, which means that it weighs the same as a globe of zinc the same size. The weight of our Earth is equal to that of a globe of arsenic the same size. The densities of the other bodies of the solar system vary considerably. That of Venus is equal to iron pyrites,

that of Mars to ruby, and that of the Moon to flint-glass. The Sun and the four large planets, although so much superior to the inner planets in size, have smaller densities. The Sun and Jupiter weigh the same as globes of dry sand the same size, while the densities of Uranus, Neptune, and Saturn are equal to those of amber, boxwood, and walnut-wood.

The key to the different velocities, densities, and masses of the planets is the marvellous power of gravitation, which was referred to in the opening chapter, and the complete investigation of which we owe to the genius of Newton. Not only the planets and their satellites, but the various comets and the systems of meteoric rings conform to this mighty law which extends throughout the entire length and breadth of the Universe. Gravitation is the marvellous invisible bond everywhere present, operating throughout all space, which keeps the planets in subjection to the Sun, and which maintains order instead of chaos, harmony instead of discordance. Much as astronomers know of the operation of gravitation, of its nature they are entirely ignorant. In contemplating this marvellous force which so far has baffled science, the mind is lifted right into the region of things Divine and Eternal.

In this chapter we have briefly referred to the system of planets surrounding the Sun. The solar system is not only a system, but a system of systems, for, as we have seen, the various planets with their satellites form subordinate systems within the larger one. To explain the outstanding features of these planets and satellites will be the task of the next few chapters.

CHAPTER VI

MERCURY—"THE SPARKLING ONE"

SO far as we know, Mercury is the nearest planet to the Sun. The existence of a world at a less distance than Mercury was suspected, and indeed generally believed in, half a century ago. There were certain irregularities in the motion of Mercury which astronomers attributed to the action of an unseen planet. One observer boldly announced that he had seen the planet crossing in front of the Sun, and so the name of Vulcan was bestowed on the supposed world. But Vulcan was never seen again, and accordingly the great majority of astronomers believe that it never was seen—in fact, that no such planet exists.

Mercury, therefore, is the nearest known planet to the Sun. Seen from the Earth, the little orb is never far from the day star. Mercury revolves round the Sun in an orbit within that of the Earth, and consequently it is never to be seen on a dark sky in the opposite part of the heavens to the Sun. In Britain, Mercury is rarely visible, so close does it keep to the orb of day. In fact, it is recorded of Copernicus, to whom we owe the true theory of the planetary motions, that although he often looked for the planet, he was never successful in seeing it. The reason of his failure is not far to seek. He lived the greater part of his life near the valley of the Vistula, in Poland, where the horizon is rarely free from mists, and

Mercury is never very far above the horizon. Notwithstanding the difficulty of seeing it, Mercury has been known from the earliest times. The ancient Greeks were well acquainted with it, and it was sometimes known to them as the "sparkling one." This name was given to it because it does not, like the other planets which rise high in the heavens, shine with a steady light. As we always see it through the more or less misty air about the horizon, it twinkles and sparkles in a beautiful manner. Hence the name which the ancient Greeks so poetically conferred on the little planet.

As Mercury, owing to its proximity to the Sun, is difficult to observe with the unaided eye, it is also difficult to observe with the telescope. The opportunities of favourable observation are few, so closely does it follow the Sun. The first thing which impresses the telescopic observer of Mercury is that the planet exhibits phases similar to those of the Moon. As the Earth's path encloses the orbits of both Mercury and Venus, we never see these planets fully illuminated. To be fully illuminated a body must be in the opposite quarter of the heavens from the Sun, like the Moon at the full phase. Sometimes, however, Mercury is at the opposite side of the Sun from our planet. That is to say, we have Mercury, the Sun, and the Earth all in a straight line, with the Sun between the Earth and Mercury. The planet is then at its farthest from the Earth, but could we observe it we should see it with a fully illuminated disc; in fact, we should have "full Mercury." We do not see the planet at these "superior conjunctions" as such occurrences are called, for Mercury is then lost in the glare of the Sun and quite invisible to the terrestrial observer. After a time, however, the planet, in its journey round the orb

of day, reappears from the solar glare as an evening star. As it comes nearer and nearer to the Earth, and as its disc becomes apparently larger, the illuminated portion decreases, until we have only "half Mercury," then a crescent Mercury, until, when the planet is at its nearest, the thin crescent disappears altogether and we soon have "new Mercury." Like our satellite at new Moon, Mercury becomes invisible. Technically it is said to be at "inferior conjunction," because the Earth, Mercury, and the Sun are in a straight line, with Mercury in the centre, the result being that the bright side of the planet is turned towards the Sun and away from the Earth. Then on its journey round the Sun, Mercury again appears as "morning star." Only a little crescent is at first visible in the telescope, but gradually the illuminated portion becomes greater as the planet recedes from the Earth and the apparent diameter decreases. Again we have "half Mercury," and again the planet disappears in the rays of the Sun to reappear as an evening star.

Thus we are placed at a disadvantage in regard to the observation of Mercury, because the planet revolves round the central orb within the orbit of the Earth. When Mercury is nearest to us it is invisible. When it is fully illuminated it is also invisible. We only see it bit by bit, as it were, at its various phases. Above all, it is so near the Sun that astronomers are never able to observe it on a dark background, and it is so low in the heavens that it is always seen through a stratum of thick air.

For many years nothing was known of the surface of Mercury. At the beginning of the nineteenth century, however, a series of observations were made by Schröter,

an able German astronomer of that day. Schröter was anxious to ascertain the period of Mercury's rotation on its axis—the length of the planet's "day." Schröter detected certain markings, and from the motions of those he concluded that the rotation of Mercury was performed in about twenty-four hours, similar to our own terrestrial day. For many years this estimate was generally accepted, although owing to the great difficulty of observing the planet it was not implicitly relied on.

Some distinguished astronomers, however, were not content with a mere unconfirmed estimate of the length of Mercury's day. Among these was Schiaparelli of Milan, who, in 1882, commenced a prolonged series of observations of the planet for the purpose of determining the rotation period. Previous observers had been handicapped by the fact that Mercury when visible as an evening or morning star is to be seen for only a short period. Therefore prolonged observations of the planet are impossible under such conditions. Schiaparelli struck out a new line. Instead of observing Mercury at the usual time, he followed it by day, considering that the disadvantage of observing the planet in the day-time was more than compensated by the advantage of prolonged observation. He followed the planet for hours at a time, and at last, after seven years' observations, he announced his discoveries. They were as startling as they were unexpected. He found that so far from the planet rotating on its axis in twenty-four hours, the markings visible remained fixed in position, and that the planet performs only one rotation on its axis during its revolution round the Sun. Instead of rotating in twenty-four hours, as the Earth does, it rotates in eighty-eight of our terrestrial days. Controversy raged for some years among astro-

nomers as to the accuracy of this result, but now the truth of Schiaparelli's discovery is generally accepted.

Let us try to imagine what sort of a world Mercury must be. Rotating on its axis only once during its journey round the orb of day, it turns the same face to the Sun just as the Moon does to the Earth. One face

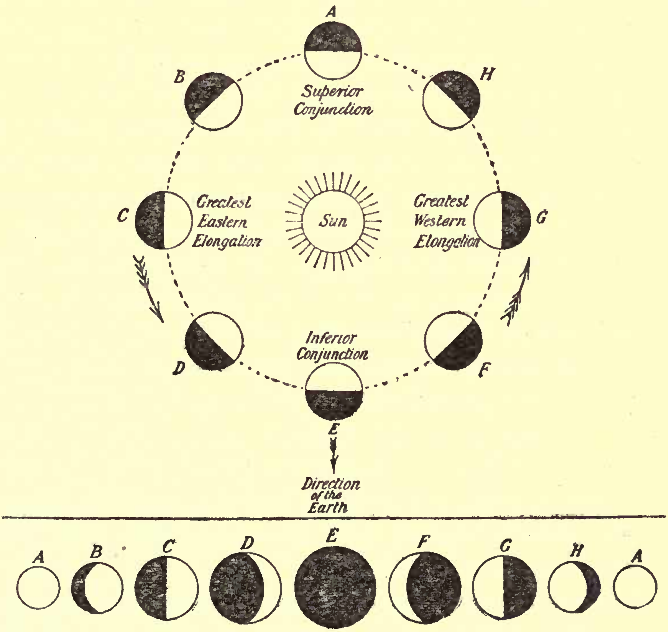


FIG. 4.—Orbit and Phases of an Inferior Planet.

of the planet is bathed in perpetual sunshine, the other is shrouded in everlasting night. One side is baked with heat, and the other is frozen with cold. No wonder that the surface, as the observations of Professor Lowell indicate, is cracked in all directions. The surface of Mercury, he says, is colourless: "a geography in black and white."

However, there is a small zone on the planet's surface on which the Sun does rise and set—owing to the irregular motion of the planet in its path, its varying velocity due to the eccentricity of its orbit, and its uniform motion on its axis. This is clearly explained by Mr. Gore in the following words: "This difference in the regularity of the two motions will of course give rise to a 'libration,' which will have the effect of bringing a portion of the dark side of Mercury periodically into the sunlight, and will thus diminish the area of the planet's surface which is shrouded in perpetual night. About three-eighths of the total surface will for ever remain in darkness, three-eighths in perpetual sunshine, while the remaining one-fourth will have alternately day and night. In fact, an inhabitant living near the mean bounding line and on the planet's equator would have forty-four days of sunshine and forty-four days of night and twilight. A little farther in on the dark side there would be perpetual twilight; and farther in still, eternal night would reign. Owing to the low altitude attained by the Sun near the bounding line, its intense heat and light would of course be much mitigated, so that probably this region of the planet's surface may be comparable with the temperate zones of the Earth."

Little is known of the markings of Mercury. The few observations which astronomers possess seem to indicate that the surface is rugged and mountainous, somewhat similar to that of the Moon. As to whether there is an appreciable atmospheric envelope surrounding Mercury, opinion is divided, some holding that the globe of Mercury is, like that of our satellite, airless, others believing that there is an atmosphere surrounding the little planet.

The general opinion of astronomers is that under such

conditions as exist on Mercury, life, as we know it, is impossible. If there are inhabitants of Mercury, they must, from the dark side of their world, obtain magnificent views of the outer universe. Venus and the Earth will shine with a glorious radiance, fully illuminated. The Earth and Moon seen from Mercury form a fine double star. The Earth will appear a magnificent object, attended by a little star of the third magnitude. The brightest object in the evening skies of Mercury will be Venus, as the little planet has no satellite circling round it and illuminating its dark hemisphere.

CHAPTER VII

THE EVENING STAR

FROM the earliest ages the planet Venus has been known to, and admired by, mankind. No record exists of the recognition of this beautiful planet as distinct from the ordinary stars, for of all the "wanderers" Venus, as the brightest, would probably be the first to be detected. Homer refers to the star as the "star of Lucifer," and one distinguished astronomer holds that under the title of "Mazzaroth" it is referred to in the Book of Job.

Venus is both the evening star and the morning star. That is to say, the phenomena known as evening star and morning star are different appearances of the same orb. The earliest astronomers amongst the Greeks did not know this. The morning star they called "Phosphorus" and the evening star "Hesperus," and for many years the two were believed to be separate bodies. It was noticed, however, that when the evening star was to be seen in the evening, there was no trace of the morning star on the following morning, and that conversely when the morning star was visible, it was hopeless to expect to see it at night at the same period. Pythagoras, the famous Greek thinker, is believed to have been first in identifying the two stars as one—the evening and morning star.

Venus, like Mercury, exhibits phases when observed with the telescope. As Venus is so much nearer than Mercury, and is a much larger planet, these phases are much more

easily observed. To the unaided eye Venus is but a luminous point, bright enough on rare occasions to cast shadows, but with no definite shape. When, however, we turn even a small telescope on the evening star, a remarkable change is wrought. The beautiful soft luminous point is transformed into an exquisite little disc of varying phases, for Venus, in Galileo's phrase, "imitates the phases of the Moon." The existence of these phases was affirmed by Copernicus when he propounded the theory of the planetary system. The existence of these phases was a necessary proof of his contention that the planets went round the Sun, and not round the Earth. It was pointed out to Copernicus that no phases of Venus could be seen, and in those days there were no telescopes. "God," replied Copernicus to his critics, "will cause instruments to be invented to improve the sight and then you will see them." Soon after the invention of the telescope, in 1611, Galileo turned his instrument on the evening star, and there, in the field of the telescope, shone an exquisitely beautiful miniature of the Moon, going through each of our satellite's phases. As a telescopic object Venus is indeed beautiful. The observation of the planet is a source of never-ending delight. No one can avoid feeling a thrill of pleasure as he beholds the beautiful evening star, shining out softly in the twilight, with its calm and rich radiance, transformed by the telescope into an ever changing golden disc, sharply defined in the evening light.

The phases of Venus are similar to those of Mercury. At "superior conjunction" the disc of the planet is fully illuminated, but it is lost in the rays of the Sun. Then the planet emerges from the sunlight as "evening star." When it reaches its "greatest elongation east," the disc is half illuminated like the Moon at the quarters. As

the planet approaches the Earth the disc increases in size, but the illuminated portion decreases until the planet, a dwindling crescent, is again lost in the rays of the Sun at "inferior conjunction," and we have "new Venus." The planet is at its nearest only some twenty-six millions of miles from the Earth, but it is invisible. Shortly after this it reappears as morning star, a thin crescent increasing in size, and its apparent diameter decreasing. When it reaches its "greatest elongation west," Venus is in its best position for observation as morning star. The disc becomes smaller, more and more of it becoming visible, until it draws close to the Sun, once again passes superior conjunction, and emerges from the sunset as evening star.

Our knowledge of the configuration of the surface of the planet is very limited, for two reasons. In the first place, Venus is, like Mercury, unfortunately placed for observation. It is, of course, easier to observe than Mercury, being much farther from the Sun and much larger, but, like that orb, it is never seen on a dark sky, and never observed for a protracted period. In the second place, the planet is so dazzlingly bright that it is very difficult to observe markings on its surface. Venus reflects a greater proportion of the light which it receives from the Sun than any other planet. As Mr. G. F. Chambers remarks in his book, "The Story of the Solar System," "the reflective power of Venus was probably never more effectively brought under the notice of a human eye than on September 6, 1878, when Nasmyth enjoyed an opportunity of seeing Venus and Mercury side by side for several hours in the same field of view. He speaks of Venus as resembling clear silver, and Mercury as nothing better than lead or zinc. Seeing that owing

to its greater proximity to the Sun, the light incident on Mercury must be three and a half times as strong as the light incident on Venus, it follows that the reflective power of Venus must be very great." This reflective power has been estimated as equal to that of newly fallen snow. The evening star reflects seventy per cent. of the light which falls on it. What is the reason of this remarkable reflective power? The generally accepted explanation is that the planet is surrounded by a very dense and cloud-laden atmosphere, and that the sunlight falls on these clouds. In other words, we rarely catch a glimpse of the surface of Venus. This is fully confirmed by observation of the planet. It is only with the greatest difficulty that the markings can be detected.

As in the case of Mercury, the length of the planet's day has been for many years a matter of controversy. Observations made in the seventeenth century by the famous astronomer, Cassini, indicated that Venus turned on its axis in a period of about twenty-three hours. At the same time, however, another astronomer, Bianchini, made observations which suggested a period of twenty-four days, eight hours. The German astronomer Schröter, tackled the question at the end of the eighteenth century, and confirmed the short period of twenty-three hours. In 1839 an Italian astronomer, Di Vico, confirmed these observations, and for fifty years the twenty-three hour period was generally accepted. It was the same distinguished astronomer who showed the probability of the long rotation period of Mercury who made the same discovery in regard to Venus.

A series of observations, extending over thirteen years, convinced Schiaparelli that the markings noted by the earlier observers were not really permanent. As in the

case of Mercury, he observed the planet by day, and was enabled to follow it for hours at a time. He concentrated his attention on round white spots which remained fixed in position. The obvious conclusion to be drawn from this is that Venus performs only one rotation on its axis in its period of revolution round the Sun—225 days. One face of the planet is constantly turned to the Sun, and in continuous sunlight; the other face is always turned from the Sun, and is in everlasting darkness. In the case of Venus there is not the same amount of "libration" as in that of Mercury. The pathway of Venus is much more nearly circular, and the variation of velocity is much less than in the case of the smaller planet, so that only a very small part of the surface will enjoy the alternation of night and day as does a considerable portion of Mercury.

Since Schiaparelli announced his results, a number of different observers have made observations to determine the rotation period. The period of 225 days has been abundantly confirmed by observers favoured by good climates and clear skies, while astronomers in less favourable climates supported the short period. It may be now taken as very probable therefore that Venus rotates on its axis in the same period as it requires to revolve round the Sun

Little is known of the physical condition of the planet owing to the dense atmosphere which surrounds it. Polar "caps," supposed by some to be somewhat similar to those on our own planet and on Mars, have been observed, or at least "suspected," from time to time. Some astronomers, however, do not regard them as snow; the drawings of Schiaparelli represent them as separated by a dark shadow, which suggests that they represent two mighty mountain systems. Evidence of the mountainous condition of Venus was obtained by Schröter as long ago as

the beginning of last century. He noted the southern "horn" of the planet when in the crescent form to be blunted, and he attributed this to the existence of a great mountain, five or six times higher than the loftiest peaks on the Earth. Along the terminator, or the dividing line between light and darkness, he noted irregularities which he considered to be more strongly marked than those on the Moon. These observations have since been only partly confirmed. Still there seems fairly strong evidence that the surface is rocky and mountainous, although not so mountainous as was believed by Schröter. Trouvelot, a French astronomer, found in 1878 the polar spots distinctly visible. "Their surface," he wrote, "is irregular, and seems like a confused mass of luminous points, separated by comparatively sombre intervening spaces. This surface is undoubtedly very broken, and resembles that of a mountainous district studded with numerous peaks, or our polar regions with numerous ice-needles brilliantly reflecting the sunshine." These features, then, are either striking enough to be seen through the dense cloud-canopy which surrounds Venus, or else they are high enough to project above the dense portions of the atmosphere.

Of the existence of the atmosphere there is no doubt. It has been actually observed when the planet is in "transit" across the face of the Sun. Spectroscopic observations show that water vapour exists in the atmosphere, which is very dense. Seen from the Earth, this atmosphere seems the very picture of calm and quiescence. But if the long period of rotation indicated by Schiaparelli's observations be correct, it can scarcely be a calm region. As a recent writer puts it: "The atmosphere circulation of Venus must be conducted by a permanent hurricane system. A violent uprush of heated air on the side perpetually

exposed to a glare twice as fierce as that of our hottest sun, should be compensated for by a furious inrush on both sides of the illuminated hemisphere, like the draught caused by a fire in a cold room."

Venus has no satellite, in this respect resembling Mercury. For many years, nevertheless, a search for a satellite was prosecuted with great energy, and it was believed by several astronomers that they had detected a companion-world. It was afterwards shown, however, that what they had taken for satellites must have been either optical illusions, caused by the glare of the planet in the field of the telescope, or small stars which happened to lie in the same field of view as the planet. Thus, although in size resembling the Earth more than any other world, it differs from our planet in several important respects; its "days" are utterly different from ours, and it has no Moon to circle round it and perform the useful offices of satellite-world.

The question of the habitability of Venus has attracted little attention. Certainly the planet, with its remarkable rotation period, and its dense atmosphere, does not seem an inviting abode. On this point, however, astronomers know too little to speak with confidence. Sir Robert Ball inclines to the view that even though Venus does rotate in the way that the majority of astronomers believe, "we might expect to find in that planet a luxuriant tropical life of a kind perhaps analogous to life on the Earth." If there are inhabitants of Venus, and if ever they catch a glimpse of the outer universe, their eyes will be gladdened by a beautiful celestial spectacle such as we on this planet are not privileged to see. The Earth and Moon, combined, probably appear more brilliant to Venus than Venus does to us, and the two orbs—the smaller moving round the larger—form a beautiful and imposing double star.

CHAPTER VIII

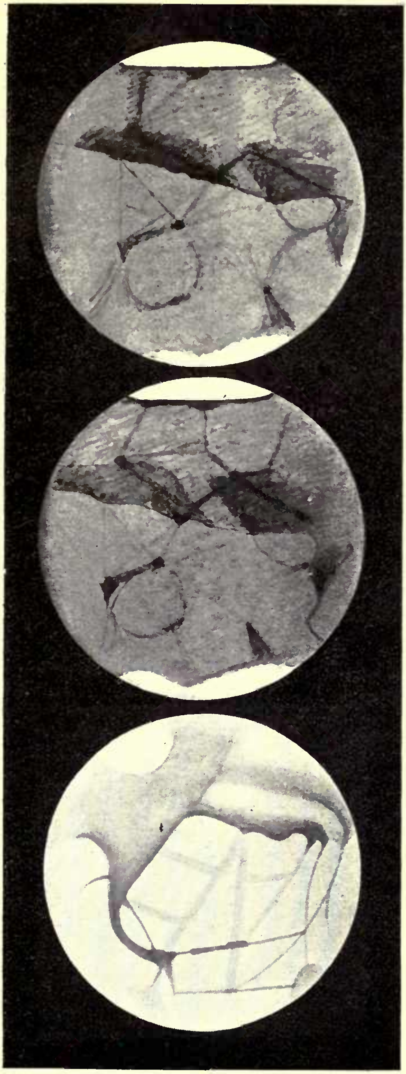
MARS—THE RED PLANET

AS was shown in the previous chapters, Venus revolves round the Sun in an orbit wholly within that of the Earth, and consequently is not seen by us to full advantage. When nearest, the planet is invisible; it is in a straight line between the Earth and the Sun, and turns its dark hemisphere to our planet. With Mars the case is entirely different. Mars revolves in an orbit exterior to ours, and when nearest to the Earth is on the other side of our planet from the Sun. The Sun, the Earth, and Mars are in a straight line with the Earth in the middle. If the near approaches of Venus correspond to "New Moon," those of Mars correspond to "Full Moon." We then see Mars with a full round disc. The planet is said to be "in opposition" to the Sun, because it is in the opposite quarter of the heavens. It rises at sunset, culminates at midnight, and sets at sunrise.

Mars as a celestial spectacle is usually inferior to Venus. But at times its brilliancy becomes extraordinary, and the planet shines with a bright ruddy light which makes it one of the most striking objects in the heavens. In the words of a famous modern astronomer: "Once in every fifteen years a startling visitant makes his appearance upon our midnight skies—a great red star that rises at sunset through the haze above the eastern horizon, and then, mounting higher with the deepening night, blazes forth

against the dark background of space with a splendour that outshines Sirius and rivals the giant Jupiter himself. Startling for its size, the stranger looks the more fateful for being a fiery red. Small wonder that by many folk it is taken for a portent." It is recorded that in 1719 Mars was so brilliant that a panic ensued among the ignorant. Owing to the comparative nearness of Mars to our world—at times about thirty-five millions of miles—along with its favourable presentation when closest to the Earth, we know more of the surface of Mars than of any other body in the entire Universe, with the single exception of the Moon. For over 250 years Mars has been attentively studied by astronomers. It was observed by Galileo, who, however, discovered nothing important. In 1656 the Dutch astronomer, Huyghens, made the first determination of the length of the Martian day, the period of the planet's rotation on its axis. Unlike Mercury, Mars has a day somewhat similar to our own, the length of which has been known for over two centuries. The exact length, to within a fraction of a second, is 24 hours 37 minutes 22·65 seconds, only about half-an-hour longer than the day of our own world. Its year, therefore, which consists of 687 of our days, contains 669 of its own. In another particular Mars closely resembles the Earth. The inclination of its axis to the plane of its orbit is about 66 degrees; its seasons, therefore, closely resemble those on the Earth. Another remarkable point of resemblance was noted almost two centuries ago. In 1719 the French astronomer Maraldi discovered two white spots on the disc of Mars—one at the north pole, the other at the south. These spots correspond to the polar regions of our own planet.

Like the Earth, Mars has an atmosphere, but it is



THE PLANET MARS

The two uppermost drawings are by Professor Lowell, July 8 and 12, 1907. The lower drawing is by Professor Schiaparelli, May, 1890. On each the polar caps and the famous canals are visible.

much thinner than our own, "thinner at least by half," says Professor Lowell, "than the air on the summit of the Himalayas." Clouds and obscurations seem to be very rare in the Martian atmosphere. It is very clear and transparent, and it is believed not to differ much from our own in constitution. The following description of this Martian atmosphere is from the pen of the late Miss Agnes Clerke: "This slender envelope is exceedingly extensive. In the pure sky, scarcely veiled by it, the Sun diminished to less than half its size at our horizons, probably exhibits its coronal streamers as a regular part of his noontide glory; atmospheric circulation proceeds so tranquilly as not to trouble the repose of a land 'in which it seemeth always afternoon.'"

Huyghens and other early astronomers detected various prominent markings, chief among them the well-known features known variously as the Kaiser Sea, the Hour-Glass Sea, and, in the now prevalent system of nomenclature, the Syrtis Major. It was not, however, until Herschel took up the study of Mars that much was known of its surface. He found that the spots at the poles waxed and waned in accordance with the Martian seasons—that is to say, the north polar cap increased in size during the winter of the northern hemisphere, and decreased in summer, while the reverse process took place in the southern hemisphere. He concluded, therefore, that the polar spots were masses of snow and ice, similar to the polar regions of the Earth. After the planet had been attentively studied by Beer and Mädler, Dawes, Secchi, and other astronomers, the late Mr. Proctor constructed a map of Mars in 1869 from drawings by Dawes. He gave names to the various features, the red portions of the planet's disc being known as continents, and the green as seas, in

accordance with the prevailing views of contemporary astronomers. Along with this he put forward in "Other Worlds than Ours," some very fascinating and plausible ideas of the habitability of Mars, which he named a "miniature of the Earth," having continents, oceans, snow, rain, clouds, rivers, and probably inhabitants. The researches of the last twenty-eight years, however, have revolutionised our knowledge of Mars. The close analogy which Proctor perceived has vanished, and Mars is now considered as an emblem of what our world will be in the future rather than as a miniature at present. The most recent observations have changed but not destroyed the analogy.

It was in 1877 that the revolution in our views concerning Mars began. In the words of Mr. Percival Lowell: "Our knowledge of the planets, and especially of Mars, has advanced greatly within the last quarter of a century. The first steps of this advance we owe not to instruments, but to the genius of one man—the Italian astronomer Schiaparelli."[1] When in September 1877 the planet reached its opposition, this famous astronomer commenced a trigonometrical survey of the planet's disc. While so employed he discovered a number of fine dark lines crossing the red areas of the planet. He called them "canali," an Italian word meaning canals or channels. In 1879 Professor Schiaparelli again observed the canals, which revealed the same appearance as they had done two years previously. Towards the end of the year he was amazed to find that one of the canals had become double—a new canal running parallel with the original one. Suspecting optical illusions he

[1] It is claimed that some of the more prominent canals had been noted by Mr. Maunder and other English observers before 1877.

changed his telescopes and eye-pieces, but was soon convinced of the reality of his observations. In 1881 he again saw the canals, double and single; and during the unfavourable oppositions of 1884, 1886, and 1888, he went from discovery to discovery. Indeed, he declared in 1888 that the canals had all the distinctness of an engraving on steel with the magical beauty of a coloured painting. Considerable scepticism prevailed in scientific circles for a number of years, as other astronomers could not see the canals, either double or single. At length, in 1886, nine years after the Italian astronomer made his discovery, the news flashed over the scientific world that his discovery was confirmed. In that year the astronomers at the Nice Observatory detected the canals. They were soon followed by a number of the most distinguished observers, both of Europe and America, who testified that the canals were there, however much astronomers might differ in their interpretation of them.

In 1892 Professor Pickering, observing in the fine climate of Arequipa, on the slope of the Andes in Peru, discovered at the junctions of the canals dark spots which he termed "lakes," in keeping with the view that the darker regions of the planet's surface are really aqueous; but his observations at the same opposition threw considerable doubt on this view. For the purpose of observing the planet thoroughly during the favourable opposition of 1894, Mr. Percival Lowell erected a special observatory at Flagstaff, Arizona. Observations were there commenced on May 29, 1894, by Mr. Lowell and his assistant, Mr. Douglass, and were continued until April 3, 1895, when the favourable season for observation came to an end. Altogether, Mr. Lowell mapped out three hundred and fifty canals, and obtained confirmatory

evidence of the existence of lakes discovered by Professor Pickering. Instead of lakes, Mr. Lowell prefers to call them "oases."

At the same time Professor Lowell made what he calls a Martian polar expedition. On 3rd June 1894 he measured the south polar cap when it stretched "almost one unbroken waste of white," over about 55 degrees of latitude, its diameter across measuring 2035 miles. As it melted there was observed surrounding it a broad blue belt, and as the cap contracted the belt, which evidently represented the water let loose by the melting of the cap, also decreased in size. In August 1894 it was, in Professor Lowell's words, "a barely discernible thread drawn round the tiny white patch, which was all that remained of the enormous snow fields of some months before." On 12th October Mr. Lowell noted in his diary: "Polar cap has been very faint for some time; barely visible." On the following day his assistant, on turning the telescope on Mars, was amazed to find that the cap had vanished. This was the first occasion on which the snow cap was seen to disappear; and this shrinkage or disappearance of the cap apparently holds the key to the various problems of the Martian disc.

By this time several theories had been put forward to account for the phenomena of the planet's surface. Proctor had thrown out the hint that the canals were rivers, but this idea was soon thrown aside. Various other astronomers regarded the canals as cracks in the planet's surface, as swarms of meteors ploughing tracks above the planet, and as chains of mountains running over land and sea; but each of these hypotheses was in turn abandoned as untenable. In the end of 1895 Mr. Lowell's views on the planet—the result of his own observations—were given to

the world in his book, "Mars." Mr. Lowell concludes that the reddish ochre portions of the planet—the "continents" of Proctor—are desert land; that the dark regions are not seas, but marshy tracts of vegetation, and that the polar caps are composed of snow and ice. He adopts Professor Schiaparelli's view that the canals are waterways, lined on either side by banks of vegetation, as well as Professor W. H. Pickering's idea that the lines which we see are not the canals themselves—which are much too small to be seen—but the strip of fertilised ground surrounding them. The canals are distinctly connected with the melting of the polar cap, and grow darker as the cap melts, just as if water was being conveyed along them. All this is very easily explained by one assumption—namely, that the canals have been constructed by a race of intelligent beings for the specific purpose of bringing water from the melting polar cap to the equator. Mars is scarce of water; and if there are inhabitants they must be compelled to utilise every drop which they can secure. The oases are supposed by Mr. Lowell to represent centres of population where the inhabitants, driven from the desert land by scarcity of water, cluster about the ground artificially fertilised. Mr. Lowell also concludes that as Mars is an older planet than the Earth, the inhabitants are probably in a higher state of civilisation. Thus, all the complicated Martian phenomena are explained on the assumption that Mars is inhabited by a race of intelligent beings.

This theory was not cordially received, and astronomers began to consider if some other explanation would not be more probable. Most scientists inclined to what is known as the "optical illusion theory," put forward originally by the eminent Italian astronomer, Signor

Vincenzo Cerulli of Teramo, and independently by Mr. E. W. Maunder, of Greenwich Observatory, the well-known English astronomer. It was supported by Professor Simon Newcomb, who thus explains the "canaliform" appearance: "This phenomenon is not to be regarded as a pure illusion on the one hand, or an exact representation of objects on the other. It grows out of the spontaneous action of the eye in shaping slight and irregular combinations of light and shade too minute to be separately made out, into regular forms." A series of experiments made by Mr. Maunder in 1902 and 1903 were described by him in *Knowledge* for November 1903. In conjunction with Mr. Evans, headmaster of the Royal Hospital School of Greenwich, Mr. Maunder arranged for classes of two hundred boys to copy at different distances three views of Mars on which the canal system was not represented. As almost all the boys drew canals on the copies, Mr. Maunder considers that the optical illusion theory is finally proved. But Mr. Lowell answers him by the following criticism of the theory:—"It asserts that because of the tendency of the human eye to connect well-seen points by imaginary lines, therefore those on Mars are of this class; which is like saying that because a man may see stars without looking at the heavens, therefore those in the sky do not exist. The parallel is not simply for illustration; it is exact, for the nervous action of the optic lobes will similarly cause any one to see faint points of light in a darkened field of vision, and the whole art of the observer consists in distinguishing which of these phenomena are objective and which not. So with these lines. A little more experience than the boys possessed would have permitted of parting the true lines from the false."

Mr. Lowell's observations on Mars, at the opposition

of 1903, were distinctly confirmatory of this theory. He made use of his various drawings "to determine the degree of visibility of a given canal at different seasons of the Martian year." After eliminating all sources of error, Mr. Lowell was able to construct graphs or curves of the visibility of the canals, and thus formed a series of curves which he named cartouches. From a discussion of these cartouches, Mr. Lowell finds that the development of the canals does not commence until the polar cap begins to melt; but after the cap melts the canals develop down the latitudes past the equator into the opposite hemisphere. He finds that it takes the water fifty days to travel from latitude 72° N. to the equator, a distance of 2650 miles. "This means a speed of fifty-one miles a day, or 2·1 miles an hour, and here we confront the surprising part of the performance, for the transference takes place in the face of gravity. A particle of water or other liquid would know no inclination to move from where it found itself. Gravity would not solicit it to stir. Of its own accord it would not move from the pole to the equator. Now, as it does flow towards the equator, and with a remarkably steady progression too, the inference seems inevitable that it has been carried thither by artificial means." In 1905 and 1907 Mr. Lowell succeeded in photographing the canals. His first photographs secured a number of converts, if not to his opinion, at least to belief in these remarkable objects.

Mr. Lowell hailed his success in 1905 as the refutation of the opposing theory. As the photographic plate cannot be the victim of illusion the canals should, on the illusion theory, be represented by irregular dots instead of straight dark lines. As Mr. Lowell remarked

in a communication to the present writer, "the camera does not agree with the arm-chair critics of the canals, but will have it that these markings are lines." Nevertheless the supporters of the illusion theory still hold to a modified form of it. In their latest work, published in the end of 1908, Mr. and Mrs. Maunder have the following remarks: "Are these markings on Mars actually as we see them, or do we only see them like that? We have no right to conclude that the straight sharp even 'canals' we see on the surface of Mars are really as artificial as they seem to us."

Some remarkable observations of the canals were made by Professor Lowell at the "opposition" of the planet in 1909. On September 30 of that year, when the region known as the Syrtis Major was presented to view, two very prominent canals became evident. "Not only," says Professor Lowell, "was their appearance unprecedented, but the canals themselves were the most conspicuous ones on this part of the disc. Many drawings were made, and in the course of the next few days the new canals were photographed, appearing on the plates as the most salient canals in their part of the planet. The record books were then examined, when it appeared that not a trace of them was to be found in the drawings of August, July, June, or May, when this part of the planet was depicted. That they had not been observed in previous years was then conclusively ascertained by examination of the records of those years."

Professor Lowell shows that these canals were never seen before, either by himself or by Schiaparelli, or by any other observer. "It might seem," he says, "that the absence on the charts was proof that a canal was itself new in the second sense, because it was so in

the first. But study of Mars has shown that this cannot be taken off-hand for granted; several points must each be carefully considered. In the first place, one must be sure that the phenomenon could have been seen before, yet was not. It must be of a size which could not have escaped detection previously. In the present case, however, this possibility of error was excluded by the size of the canals in question."

Mr. Lowell in his announcement of the discovery merely says that the proofs are clear that two new canals have developed. The inference in harmony with the theory which he maintains, that the canals are artificial, is that two new waterways have been constructed by intelligent beings. A good deal of scepticism has been aroused by a theory so startling, and few astronomers seem inclined to follow the American astronomer in the latest development of his theory. Still, if the theory in its general outline be correct, there is nothing either impossible or fantastic in Professor Lowell's explanation of the remarkable change which he has observed on the surface of Mars. Considerable space has been given here to the various theories of the canals, because these remarkable objects have not only attracted widespread attention, but have for years constituted a different astronomical problem.

As was pointed out at the beginning of this chapter, more is known of the surface of Mars than of any other body except the Moon. Our knowledge of the planet's geography, or rather "aerography," is well-nigh complete. As Professor Lowell says: "Aerography is a true geography, as real as our own. Quite unlike the markings on Jupiter and Saturn, where all we see is cloud, in the markings on Mars we gaze upon the actual surface

features of the Martian globe. They change in appearance, indeed, according to times and seasons, but they alter as true surface features would, not like cloud belts that gather to-day and vanish to-morrow." For these markings a number of different systems of names have been in vogue. Proctor was the first to draw up a real geography of the planet. He named the features after well-known astronomers, such as Herschel Continent, Mädler Continent, Dawes Ocean, Kaiser Sea. Flammarion drew up another chart, with a different set of names. For instance, the Kaiser Sea became in Flammarion's system, "Mer du Sablier." Green, another English astronomer, invented another system. Finally Schiaparelli re-named all the features on the disc, and in this nomenclature he is followed by Lowell and most modern students of Mars. His names are drawn from classical mythology, and, being Latin, have the advantage of commending themselves to astronomers of all nations. In this system the Kaiser Sea—the best known object on the red planet—becomes the Syrtis Major. The canals are named after mythological and real terrestrial rivers. Thus we find on Mars the Euphrates and the Ganges. This system devised by Schiaparelli is now in general use.

The canals vary greatly in length and in width. Many of them are about 2000 miles long. One known as the Eumenides-Orcus is 3540 miles, altogether an enormous length on a globe as small as Mars. The larger canals are estimated as from fifteen to twenty miles in width, and the smaller from two to three miles. As to their number, several hundreds have been catalogued by Schiaparelli and Lowell, and as the last-named astronomer says, "their name collectively is legion; while to name them individually is fast getting, for the number

detected, to be impossible." The geography of Mars is truly a marvellous one, so much does it resemble, and at the same time so much does it differ from our own. Whatever be our opinion of Professor Lowell's theory of their development, there is no doubt that Mars is relatively a much older world than the Earth, and that we see in it a world nearer to the end of life than our own, although relatively much younger than the Moon. For, as has been well remarked, "in space there are both cradles and tombs.

Mars has two satellites, which were discovered in the memorable year 1877. For forty or fifty years astronomers searched for satellites to the red planet. It was felt that as the Earth had one satellite, and Jupiter four, Mars should have at least one, if not two. But up to 1877 the search had been in vain. In that year, however, the late Professor Asaph Hall, aided with the large telescope of the Washington Observatory, detected two minute little satellites which circle round the red planet. In several respects these little satellites differ considerably from our satellite the Moon. In the first place, the Moon is comparatively a large body. These satellites of Mars, on the other hand, are very small. The diameter of Phobos, the nearer of the two to Mars, is estimated at 36 miles, that of Deimos, the more distant, at 10 miles. In the second place our satellite is at a considerable distance from the Earth—about 238,000 miles. The moons of Mars are comparatively close to their primary. Deimos revolves at a distance of 14,600 miles; Phobos at a distance of 5800 miles. Thirdly, our Moon is a leisurely body. It requires about 27 days to complete its circuit of the Earth. The Martian satellites are remarkable for the extraordinary rapidity of their motions. Deimos, the more distant of the two, revolves round Mars in 30 hours 18 minutes, while

Phobos completes a revolution in 7 hours 39 minutes. Now Mars requires over 24 hours to rotate on its axis. Phobos therefore revolves round Mars more than three times in one Martian day, an extraordinary state of affairs. As it revolves more swiftly than the planet rotates, it will not, like our Moon, seem to rise in the east and be carried westward, the result of the Earth's rotation in the opposite direction. This Martian satellite rises in the west, and crosses the heavens three times in one day. It overtakes Deimos and eclipses it, and runs through all its phases in eleven hours. Each phase lasts only three hours. Imagine a world with a Moon which could be seen in early evening at first quarter, and three hours later at the full. The satellites are so small, however, that they can be of little use to Mars in illuminating the evening skies.

If there are inhabitants of Mars, their skies will appear the same as our own. The stars and constellations are identical, but of course the different bodies of the solar system are differently seen. An able astronomical writer explains the appearance of the planets from Mars in the following words: "Jupiter is magnificent from Mars; it appears to the Martians half as large again as it seems to us, and his satellites should be easily visible to the naked eye. Saturn is likewise very brilliant, Uranus is easily visible, and they might have discovered Neptune before we did. They must have distinguished with the naked eye a large number of the small planets which revolve between their orbit and that of Jupiter. Mercury, drawn closer to the Sun, and lost in his rays, is almost impossible to distinguish. Venus appears to them as Mercury does to us. As for the Earth, how do they see it? . . . We are for that planet (Mars) a brilliant star presenting an aspect similar to that which Venus presents to us preceding

the dawn, and following the twilight; in a word, we are to the inhabitants of Mars the shepherd's star. Our natural vanity, then, might delude us with the idea that the inhabitants of Mars contemplate us in their evening skies purpled with the last solar rays; that they admire us from afar; that they have discovered our phases and those of the Moon as we have discovered those of Venus and Mercury; and that they suppose our world to be an abode of peace and happiness. Perhaps, even, they raise altars to us. What a disillusion if they could observe us a little nearer."

CHAPTER IX

THE ASTEROIDS

THE orbit of Mars marks the limit of the inner group of planets. These are separated from the outer group by what is variously known as the zone of asteroids, planetoids, or minor planets. They are, indeed, the most minute of bodies. Unlike their mighty neighbour Jupiter, and their comparatively large neighbour Mars, they are not to be seen without the aid of a telescope. The discovery of this zone belongs therefore to comparatively recent times, although the existence of one or more planets between the orbits of Mars and Jupiter was suspected fully three hundred years ago. In fact, Kepler, who gave to the world the "three laws" of planetary motion, predicted that a planet would be found revolving between the two bodies.

Belief in the existence of such a planet was strengthened, when, in 1772, a German astronomer named Bode investigated a curious relationship, since known as Bode's Law, connecting the distances of the planets. If we write down the following numbers, of which each after the second is double that preceding it—0, 3, 6, 12, 24, 48, and 96—and add four to each, we have another series—4, 7, 10, 16, 28, 52, and 100. Now it is a remarkable fact that these numbers represent approximately the proportions of the distances of the various planets from the Sun. Bode pointed out that 4 corresponded to the distance of Mercury, 7 to that of Venus, 10 to that of the Earth, 16 to that of

Mars, 52 to that of Jupiter, and 100 to that of Saturn. In 1781, another planet, Uranus, was discovered, and it was found that it filled the number 196. But there was not a planet at a distance corresponding to 28 between the orbits of Mars and Jupiter. Bode noted this fact, and stated his belief in the existence of a planet to fill the vacant space. In 1800, Von Zach, another German investigator, summoned a congress of astronomers to make a search for this remarkable body, whose existence was believed in before it was glimpsed by human eye. The Zodiacal region of the heavens was divided for the purposes of the search into twenty-four zones, each of which was assigned to a particular astronomer. Some astronomers were unaware of the fact that a zone of the heavens had been laid aside for their own particular attention. Among those who did not at the end of 1800 know of his own position among the band of searchers was Piazzi, the director of the Observatory at Palermo, in Sicily. On the first night of the nineteenth century—January 1, 1801—Piazzi was making observations for the purpose of forming a star catalogue when he noted particularly an eighth magnitude star. On the following night he ascertained that this was not one of the stars proper, but a body possessed of an appreciable independent motion. At first Piazzi believed that he had discovered merely a faint comet, but he soon came to the conclusion that he had found the missing planet. Accordingly he wrote to Bode at Berlin informing him of his discovery. Piazzi continued to observe the strange object for six weeks when he became unwell. By the time he was able to observe again the planet was invisible in the rays of the sun, and astronomers were afraid that it had been found only to be lost. However, an orbit was calculated from the few observations made by Piazzi,

and on the last day of 1801 the planet was again observed. It received the name of Ceres at the suggestion of the discoverer.

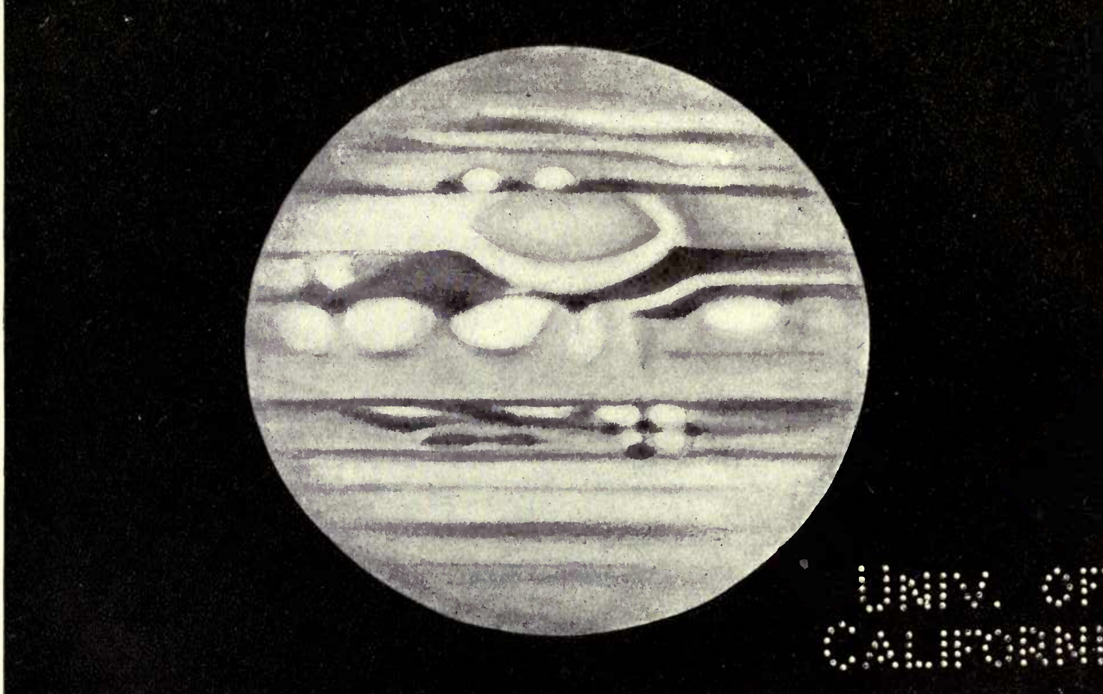
The gap had now been filled. The planet, it was true, was not comparable in size with any of the known planets of the solar system. It was so faint as to be invisible to the unaided eye. Still, astronomers believed that the missing planet had been found, filling the vacant space 28 of Bode's numerical progression. The solar system was now regarded as complete. Only three months after Ceres was rediscovered this opinion was rudely overturned. Olbers, a famous German astronomer, followed closely the new planet Ceres in the months following its rediscovery, and on March 28, 1802, he was astonished to find quite close to the position of Ceres another strange star of the eighth magnitude. A few hours showed him that this object was in motion. Here was a remarkable discovery. Not one, but two planets, revolved in the vacant space; and the new body—which received the name of Pallas—was found to revolve round the Sun at nearly the same distance as Ceres. The two bodies were without doubt akin to each other. The symmetry of the solar system was supposed to be broken, and no one was more astounded at the existence of two planets where one alone was expected, than Olbers, the discoverer of Pallas. At length he put forward his explanation of the presence of two small bodies. He supposed that there had existed between the orbits of Mars and Jupiter a large planet, of a kind similar to the other worlds of the solar system, and that, through some terrific catastrophe, this planet had in the remote past been shattered to fragments. He predicted that many more such fragments as Ceres and Pallas were likely to be found, and recommended that a search be made for other portions. In

1804, Harding, another German astronomer, discovered a third fragment, which was named Juno; and in 1807 Olbers, who had been maintaining a close watch, detected a fourth. The new planet was named Vesta, and is the brightest, though not the largest, of the asteroids. These four bodies were named the asteroids or planetoids, and for about forty years the system was again regarded as complete. It may be stated here that the theory of Olbers, although it led to the discovery of other two "fragments," is not now accepted by astronomers.

As no further asteroids seemed to be forthcoming, the search was abandoned in 1816. Fourteen years later, however, it was resumed. A German amateur astronomer, Hencke, ex-postmaster of Driessen, in Prussia, began to search for further members of the asteroid system. For fifteen years he watched without success. But at last, in December 1845, he discovered a fifth asteroid, which received the name of Astræa. A year and a half later he detected yet another, known as Hebe. In the same year an English astronomer, Hind, detected Iris and Flora, other two members of the system. Since 1847 not a single year has passed without the discovery of one or more asteroids. Some astronomers devoted almost all their time to the search for and discovery of minor planets. Peters, an American astronomer, discovered forty-eight. Palisa, an astronomer of Vienna, found over eighty, while Goldschmidt, Luther, Chacornac, and other observers each discovered many of these small planets. The method of discovery adopted by these astronomers was to construct charts of the regions round about the ecliptic in which such planets were likely to be found, and to compare those charts with the actual appearance of these regions of the

heavens through the telescope. By this method it was easy to pick out unfamiliar stars and identify them as new asteroids. This method, however, has now been discarded. A new method was devised in 1891 by Professor Max Wolf of Heidelberg, who has discovered over a hundred asteroids. It occurred to Dr. Wolf to apply photography to the detection of these objects. It is obvious that an asteroid, owing to its appreciable motion, will be represented on a photographic plate not as a point of light like the stars in the background, but as a streak of appreciable length. As Professor Brashear explains: "When the picture is developed, the stellar images show themselves as small circular dots, but if a planet were in the photographic field during the exposure, its image would be that of a very short line or trail about one-twentieth of an inch long, because it has an average movement through space of a little less than half the diameter of the Moon in twenty-four hours, while the stars remain practically stationary. This tiny trail is the clue to a new planet, or perhaps one already discovered." Since 1891 this method has been used extensively. In less than two years Dr. Wolf discovered seventeen asteroids. During the past eighteen years many minor planets have been detected in this way by Wolf and his assistants, and by Charlois, Metcalf, and other observers. The number of known asteroids now stands at about seven hundred.

By the time Dr. Wolf applied his photographic method popular interest in the ever-increasing family of little planets was on the wane. Mr. G. F. Chambers in 1895 described the asteroids as "of very little interest to anybody." It was hinted that there was no use continuing a search for bodies which so closely resembled



From a drawing by the Rev. Theodore E. R. Phillips, M.A., F.R.A.S.

THE PLANET JUPITER

The Giant Planet as seen at 11.30 p.m., on January 11, 1908, with a 12¼-inch reflecting telescope. The extensive oval marking in the upper portion of the disc is the "Great Red Spot." The south is at the top of the picture, the view being the *inverted* one given

each other, and the discovery of which served no useful purpose to the discoverer. Certainly, it must have been a singularly uninteresting search for the astronomers who prosecuted it, because with so many asteroids already discovered there was always the possibility that the newly found object might not be a new asteroid at all, but merely a known one which had been lost to astronomers. Great care had to be taken to insure that the same planet was not "discovered" twice and regarded as two different objects. As Professor Turner, of Oxford, remarks: "There was a system of numbering in existence as well as of naming, but it was inadvisable to attach even a number to a planet until it was quite certain that the discovery was new, for otherwise there might be gaps created in what should be a continuous series by spurious discoveries being struck out. Accordingly it was decided to attach at first to the object merely a letter of the alphabet, with the year of discovery as a provisional name. The alphabet, however, was run through so quickly, and confusion was so likely to ensue if it was merely repeated, that on recommencing it the letter A was prefixed, and the symbols adopted were therefore AA, AB, AC, &c. After completing the alphabet again the letter B was prefixed, and so on." This was getting tiresome to the astronomical world, until at length in 1898 an insignificant little object was discovered on a photographic plate by Witt in Berlin, and designated as D.Q. It was seen that this was a real discovery, and to the little body was assigned the number 433, and the name of Eros. It soon appeared that this asteroid was of more interest and use to the astronomer than all the other asteroids put together. The vast majority of the asteroids have their orbits between the paths of Mars

and Jupiter, but this little planet revolves in an orbit so elliptical that at its nearest position to the Earth it comes within the orbit of Mars, and is only 13½ millions of miles from the Earth. It is at times our nearest planetary neighbour, but is so faint that it is never to be seen without the aid of a telescope. It can, however, be photographed, and in this way is of the greatest use to the astronomer. By means of observations on a body so near, its distance, and thus the scale of the whole solar system, is very easily calculated. The little planetoid therefore has supplied astronomers with perhaps the most reliable measurements of the actual scale of the solar system. Since 1898 the discovery of asteroids has gone on at the same rate, but no further objects of interest have been found.

Although the asteroids are, generally speaking, akin to one another, and form a distinct zone in the solar system, they have their own individual differences. Their periods of revolution vary considerably from about three to nine years. Some of the orbits are very elliptical in shape, and, unlike the large planets, many of them do not move almost exactly in the plane of the ecliptic. Pallas, for instance, moves in a path which is inclined to the ecliptic at an angle of thirty-four degrees. In size, also, there are great differences. The four earlier discovered asteroids—Ceres, Pallas, Vesta, and Juno—are the largest. These are the only asteroids which actually show measurable discs and can thus be actually measured, and it is only by the aid of the largest telescopes in the world that such measurement can be made. Ceres is 477 miles in diameter, Pallas 304 miles, Vesta 239 miles, and Juno 120 miles. Vesta is the brightest of the four, so its surface must be highly reflective. The sizes of the

smaller planets have not been measured, but can be estimated, and it is believed that few of them have a greater diameter than twenty-five miles. Practically nothing is known of the physical nature of these minute planets. Professor Barnard observed the four larger ones carefully some years ago with the large telescope of the Lick Observatory, and saw no traces of atmosphere round them. Nothing is known either of their rotation or of the actual condition of their surfaces. Some of them are variable in light, and it is supposed that such variation is caused by the different reflective powers of the different hemispheres, combined with the rotation of the planetoids on their axes. These variable asteroids probably have rugged surfaces on which the amount of light reflected varies considerably.

The asteroid group is one of the most remarkable features in the solar system. It is obvious that one large planet is replaced by many little ones; it is also obvious that the zone divides the two groups of Inner Planets and Outer Planets, and thus separates the solar system into two portions. The existence in the solar system of this group of minute bodies all but innumerable, each pursuing its own appointed path round the orb of day, is another example of the variety and harmony of Nature.

CHAPTER X

JUPITER, THE GIANT PLANET

ONCE in about every thirteen months there reaches the meridian at midnight one of the most brilliant objects in the sky. Rising about sunset in the east, it gradually ascends until it is due south at midnight and in "opposition" to the Sun. For some time after opposition it is the most brilliant object in the night skies, and as such commands the attention of even the most casual of star-gazers. For Jupiter so far outshines all the stars in its vicinity that there can be no doubt in identifying the great planet. It reigns supreme, shining with a steady light, not so soft as that of Venus, but sharper and more sparkling. As Flammarion remarks: "When Jupiter shines among the stars of the silent night, and when our gaze is fixed on him, who would suppose, while admiring this simple luminous point, that it is an enormous and massive globe, weighing over three hundred times more than the planet which we inhabit, and of which the colossal volume exceeds by nearly thirteen hundred times that of the Earth? We have our eyes fixed on him, his light is so vivid that it casts a shadow like that of Venus, but we do not guess the marvellous grandeur of this distant body." Of all the planets Jupiter is the easiest to observe telescopically. The smallest instrument will show that it is a planet with a round disc, and will give us a glimpse of the four satellites of the planet discovered by Galileo in 1610, over three hundred years ago. Great must have been

the delight and wonder of the great Italian astronomer when, pointing his newly constructed telescope to Jupiter for the first time, he beheld the luminous point of light transformed into a flat disc, with four little points of light circling around it. A two-inch telescope gives a very striking view of the planet. On a clear night such an instrument enables us to see on the disc two or three parallel strokes, as it were. This is our first glimpse of the famous belts of Jupiter, which were first discovered after the time of Galileo. It requires a much larger instrument to bring out the principal features of the belts. With a good telescope we may view what an American astronomer thus vividly describes: "Belts of reddish clouds, many thousands of miles across, are stretched along on either side of the equator of the great planet; the equatorial belt itself brilliantly lemon-hued, or sometimes ruddy, is diversified with white globular and balloon-shaped masses, which almost recall the appearance of summer cloud domes hovering over a terrestrial landscape, while towards the poles shadowy expanses of gradually deepening blue or blue-grey suggest the comparative coolness of those regions which lie always under a low Sun." The belts are not permanent markings; they are belts of cloud, and as such are continually changing. Still, they are not so fleeting as the clouds in our own atmosphere. Some of the Jovian features, indeed, are more or less permanent. Chief among these must be mentioned an object known as "the great red spot." It was first noticed by a number of observers in the summer of 1878, and described by them as a pale pinkish, oval spot. In 1879 it became much more prominent. The pinkish hue gave place to brick-red, while the entire object extended 30,000 miles from east

to west, and 7000 from north to south. The area of the spot was no less than 200 million square miles, greater than the area of the entire terrestrial globe. For three years the spot was a brilliant object, the most prominent feature on the globe of Jupiter, lying immediately south of the great equatorial belt of the planet. Then it began to fade, and an observation by Ricco at Palermo in 1883 was thought to be the last. But in a short time it revived and again became the most prominent object on the planet's disc. Again it faded considerably, but it is still visible, a permanent feature of Jupiter's disc.

This marvellous spot has for many years attracted the attention of astronomers all over the world. Many speculations have been made as to its nature, and it is difficult to ascertain the exact cause of the appearance in a cloudy atmosphere of a permanent feature lasting so many years. Mr. W. F. Denning, one of the most devoted observers of the planet, gives as his opinion "that it represents an opening in the atmosphere of Jupiter through which in 1878–82 we saw the dense red vapours of his lower strata, if not his actual surface itself. Its lighter tint in recent years is probably due to the filling in of the cavity by the encroachment of durable clouds in the vicinity." Another remarkable fact in connection with the spot was ascertained by the American astronomer Professor Barnard. "One of the most interesting features of the great spot," he said, "was the repulsion it seemed to exert upon adjacent markings on the planet. For a time it was surrounded by a sea of light that completely encircled it for a distance of three or four thousand miles, and which appeared as a visible barrier against the approach of any spot or marking."

Observations on various spots and belts many years ago revealed the fact that Jupiter rotated on its axis

in a little under ten hours. The most exact determination fixes the rotation period at 9 hours 55 minutes 36·56 seconds. Thus Jupiter's "day" is very much shorter than that of the Earth, notwithstanding the size of the mighty planet. The curious point, however, about the rotation of Jupiter, as ascertained from observations on the red spot and other markings, is that, like the Sun, its rotation is not uniform. According to one astronomer, no fewer than nine different rotation periods are found. There is not much difference, it is true, between the various periods, but this difference gives rise to curious results. Some bright spots round about the equator actually overtake the red spot at the rate of 260 miles an hour. All these facts go to prove that in Jupiter we have a world of a different type from the four inner planets. In the case of Mars, for instance, we see the actual surface of the planet. The markings may change in accordance with the seasons, but they are always to be seen, and the rotation period derived from them is constant and unchanging. In the case of Jupiter we never see the actual surface. A remarkable thick atmosphere enshrouds the planet, an atmosphere quite unlike our own. We cannot compare the Jovian markings to our terrestrial clouds. A cloud on the Earth is a fleeting thing. It does not last for days, still less for thirty-two years. The red spot in Jupiter's atmosphere has been seen since 1878.

It is quite obvious, therefore, that Jupiter is a body of quite a different order from our own world. In many ways it resembles the Sun more than the smaller planets. Indeed, in 1879, Brédikhine of Moscow observed on the Jovian disc a group of "faculæ" similar to those of the Sun. Some astronomers believed that the markings on Jupiter, like those on the Sun, are regulated by an eleven-year period,

but this is not absolutely certain. At all events, observations of Jupiter during the last fifty years have abundantly shown that it resembles the Sun more than the Earth.

It used to be believed that the atmosphere was something similar to our own, but much more dense, and that the cloud belts were analogous to the trade winds on our planet. But the impossibility of this view was long since demonstrated. The clouds on the Earth are raised by Sun heat. Jupiter is at a much greater distance from the Sun than the Earth is, and yet it possesses an atmosphere much more dense and cloudy than ours. The explanation is obvious—Jupiter is very much larger than the Earth; it is a world in a state of chaos, "without form and void"; it is in a condition of great heat, so that the vapours, instead of settling on the surface in the form of oceans, are boiled off the fiery surface, as it were, and kept suspended in the atmosphere in the form of dense cloud masses. Jupiter seems to be in a very primitive condition, somewhat similar to Saturn, and probably Uranus and Neptune, and it throws an interesting sidelight on the previous condition of our own world.

For some time astronomers believed Jupiter to be slightly self-luminous, but this view has not been confirmed. The planet probably gives out an appreciable quantity of heat, but it is likely that its days of shining by its own light are ended. Very probably the surface is only now becoming solidified, and enormous volcanic disturbances are of daily occurrence in the semi-liquid planet. Of course this is but speculation, for the atmosphere is so dense that it is quite impossible to see it. From the surface of the planet—whether it is a solid or a semi-liquid surface—no glimpse of the outer universe is visible. Supposing, however, that an observer on Jupiter could

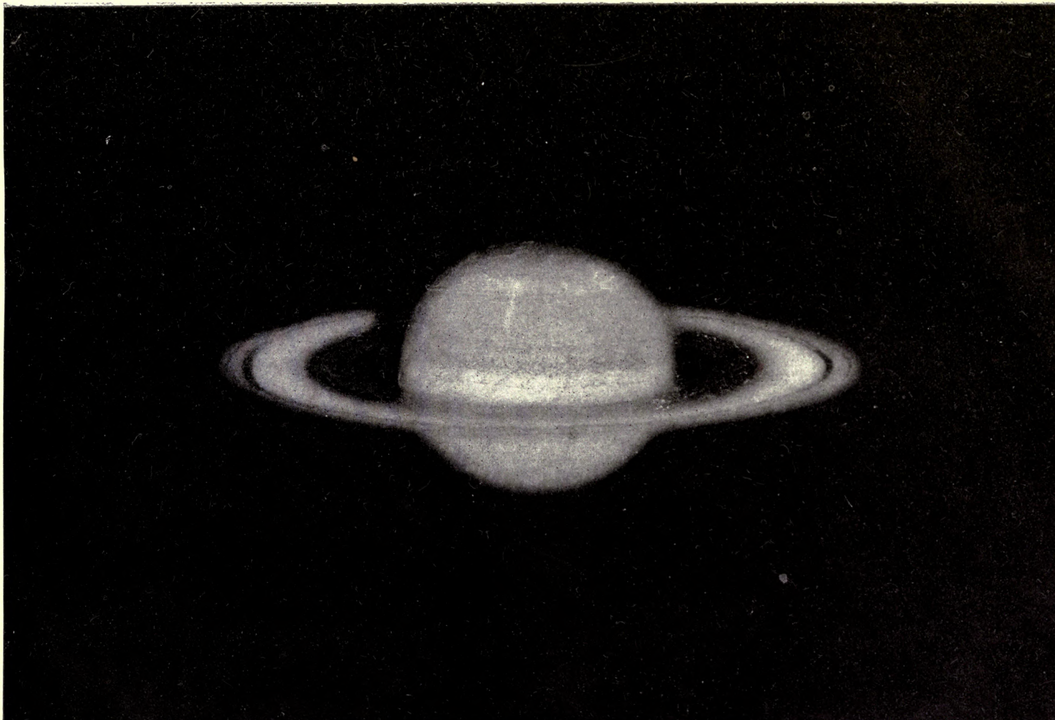
see through the cloud belts, the Earth would be hardly visible, being only seen with difficulty in the vicinity of the Sun. "At night," says a famous astronomer, "the spectacle of the sky seen from Jupiter is, with reference to the constellations, the same as that which we see from the Earth. There, as here, shine Orion, the Great Bear, Pegasus, Andromeda, Gemini, and all the other constellations, as well as the diamonds of our sky. The 390 millions of miles which separate us from Jupiter in no way alter the celestial perspectives. The most curious spectacle of this sky is unquestionably the spectacle of the four moons." To these moons Jupiter acts as a miniature Sun, giving out an appreciable amount of heat as well as reflecting the heat of the Sun. Jupiter is attended by no fewer than eight satellites, four large and four small. The discovery of the four large satellites was one of the greatest in the history of astronomy. In 1610, Galileo, at Padua, turned the newly-invented telescope on Jupiter, and discovered that the giant planet was surrounded by four satellites. The discovery was hailed with great joy by the supporters of the Copernican system. Here was a miniature of the solar system disclosed by Galileo's telescope, which ought to convince even the most sceptical. But the opponents of the new system would not be convinced, and regarded the discoverer with very unfriendly feelings. One Italian student refused to look through the telescope lest he should see the satellites. Another consented to observe Jupiter, and was immediately convinced that the satellites existed; while a third declared that even though he saw the satellites through the telescope he would not believe in them, declaring that they were in the telescope and not in the sky.

The four satellites are sometimes known by the name

of Io, Europa, Ganymede, and Callisto, though they are more frequently designated by the numerals I., II., III., and IV. The nearest satellite, Io, revolves round Jupiter in 1 day 18 hours 27 minutes, at a mean distance of 261,000 miles. Its diameter measures about 2500 miles. The second satellite, Europa, the smallest of the four, with a diameter of 2100 miles, revolves round the primary in 3 days 13 hours 13 minutes, at a mean distance of 415,000 miles. The third moon, Ganymede, is the largest of the four, its diameter measuring 3550 miles. It is, therefore, larger than the planet Mercury. It moves round Jupiter in 7 days 3 hours 42 minutes, at a mean distance of 664,000 miles. Callisto, the fourth satellite, with a diameter of 2960 miles, revolves round the primary at a mean distance of 1,167,000 miles in 16 days 16 hours 32 minutes.

These satellites are among the easiest objects of observation to the amateur astronomer. The smallest telescopes will show them, and they are a source of never ending pleasure. They may be seen sometimes in transit across the disc of Jupiter, while sometimes we are able to witness their immersion in the shadow of the giant planet and consequent eclipses, while at times we see Jupiter's disc pass over one or more of the satellites and obscure them from view. This phenomenon is known technically as an "occultation."

A small telescope will not show surface markings on the discs of the satellites. Even with the largest and best instruments, astronomers have learned little of the constitution of these moons. As to size, the two largest are of planetary bulk and dimensions. The four satellites combined form one 6000th part of the mass of Jupiter, and their volumes form one 7600th part of the volume of the



From a photograph by Professor Lowell, taken at the Lowell Observatory, Arizona, September, 1909

SATURN, THE RINGED WORLD

giant planet. Hence we see that while three of the satellites are absolutely larger than our Moon, all four are, in comparison to Jupiter's bulk, relatively much smaller bodies. The satellites seen from Jupiter's surface cover an area of the sky larger than the area filled by our Moon, but they are much less brilliantly illuminated, owing to the much greater distance of the Jovian system from the Sun. The total amount of light reflected from all four satellites at once is only one-sixteenth of that reflected by the full Moon as seen from the surface of the Earth.

For over 280 years the system of Jupiter was regarded as complete. The four satellites had been known for a long period, their motions had been carefully calculated; in fact, astronomers were thoroughly acquainted with all the details of the Jovian system. Great was the surprise among astronomers when in September 1892 it was announced that an American astronomer had discovered a fifth satellite. On the ninth of that month Professor Barnard, while observing Jupiter with the great telescope of the Lick Observatory in California, detected a minute speck of light near the planet. A series of observations proved that this was indeed a new satellite of Jupiter, closer to the planet than any of the other moons. It revolves round Jupiter in 11 hours 57 minutes, at a mean distance of 112,000 miles. It is very much smaller than the other satellites, for its diameter is little over a hundred miles.

In 1905 two other satellites of Jupiter were discovered by Professor Perrine at the same Observatory. Both of these minute objects were discovered by the aid of the photographic plate. The sixth satellite revolves round Jupiter in 242 days, at a mean distance of 6,968,000 miles. The seventh satellite is slightly closer to the planet, round which it moves in 200 days, at a mean distance of

6,136,000 miles. Early in 1908 came the announcement of the discovery of another satellite. The eighth moon, also very small and faint, was discovered by Mr. Melotte, assistant at the Royal Observatory, Greenwich, with the aid of photography. It is at a much greater distance from the planet than the other satellites, and revolves round Jupiter in the opposite direction. In astronomical language its motion, instead of being direct, is retrograde. In this respect the most distant satellite of Jupiter resembles the most distant satellite of Saturn, as will be explained in the next chapter. It is quite possible that there may be other satellites still undiscovered.

The system of Jupiter is as interesting as it is beautiful. So far as is known at present, the planet has eight satellites, four of almost planetary dimensions, four of what may be called asteroidal size. The system is more beautiful and complex than Galileo and the earlier astronomers imagined. As to the possibility of life in the Jovian system, the reader will have been able to judge from the physical condition of the planet that no life, akin to life as we know it, can possibly exist at the present moment. That it may be inhabited at some future time when the cloud belts roll away, and the vapours settle on the surface as oceans, is quite possible. Some astronomers believe that the satellites are likely to be inhabited, and certainly the four larger moons seem the more likely bodies in the Jovian system on whose surfaces life may exist. To these moons Jupiter will be a semi-sun radiating, if little or no inherent light, at least a vast amount of inherent heat. But of the actual surfaces of the satellites we know practically nothing. Marvellous and complex as is the system of Jupiter, it is simple compared to that of Saturn, to the consideration of which the next chapter is devoted.

CHAPTER XI

SATURN, THE RINGED WORLD

IN ancient days when astrology had sway over mankind, the planets were believed to influence the destinies of mortals. To be born under the planet Jupiter was to be sure of a career marked by good fortune and distinguished by glory. Mars was the god of war, and those born under the sign of that planet were characterised by martial deeds and military renown. The favourites of Mercury had the arts as their special sphere, while Venus held sway in the realms of love. Saturn was known as the unlucky planet. Its slow motion and its dull leaden light betokened gravity and gloom, and those born under its sign were called "saturnine," and were thought to be dull and morose in their natures, and to be destined to grief and calamity. To the unaided eye Saturn appears as a star of the first magnitude, with none of the brilliancy of the other planets. It has nothing of the steady brilliance of Jupiter, the soft luminosity of Venus, or the fiery red light of Mars. Consequently the ancients thought Saturn by far the least interesting of the planets, and indeed, when it is examined with the unaided eye, we are inclined to accept their opinion. But with a powerful telescope we gain quite a different idea of Saturn. So far from being the least interesting of the planets, it is the most interesting. Indeed, it is absolutely unique in the solar system, and so far as is known, in the Universe.

When we turn the telescope on it we behold a glorious orb. Its disc is striped with belts similar to those of Jupiter, only fainter owing to its greater distance. A wonderful system of three rings surrounds the planet—two bright, and one of a dusky hue. These are perfect in symmetry and exquisite in beauty. Our sense of the marvellous is deepened when it is borne in mind that these rings are not less than 176,000 miles in diameter and 30,000 miles in width, and not more than from fifty to one hundred miles in thickness. Telescopic contemplation of this magnificent planet, with its imposing system of rings, fills the mind with feelings of wonder and awe. As Flammarion puts it: "When we think that there is here a celestial deck on which the entire globe of the Earth might roll like a ball on a road, and that the world poised in the centre is several hundred times larger than our planet, we transport ourselves easily in thought to those sublime regions."

The system of rings which encircle Saturn has been known to astronomers for two and a half centuries. To Galileo they were a source of much perplexity. His telescope was not powerful enough to disclose their true nature. When he first observed Saturn it seemed to him to be oval-shaped, and this appearance he believed to be due to the fact that the planet was in reality triple, consisting of a large central body with a smaller orb on each side, "like two servants who help old Saturn on his way." Accordingly, he announced that the planet was triple. Some time later he concluded that the appearance pointed to the existence not of a triple planet, but of an orb oval in shape. Great was his surprise when two years afterwards he found that the planet had become round again. We now know that these appearances are due to the periodical vanishings of the rings, owing to the fact that as Saturn moves onward in its orbit, we sometimes behold

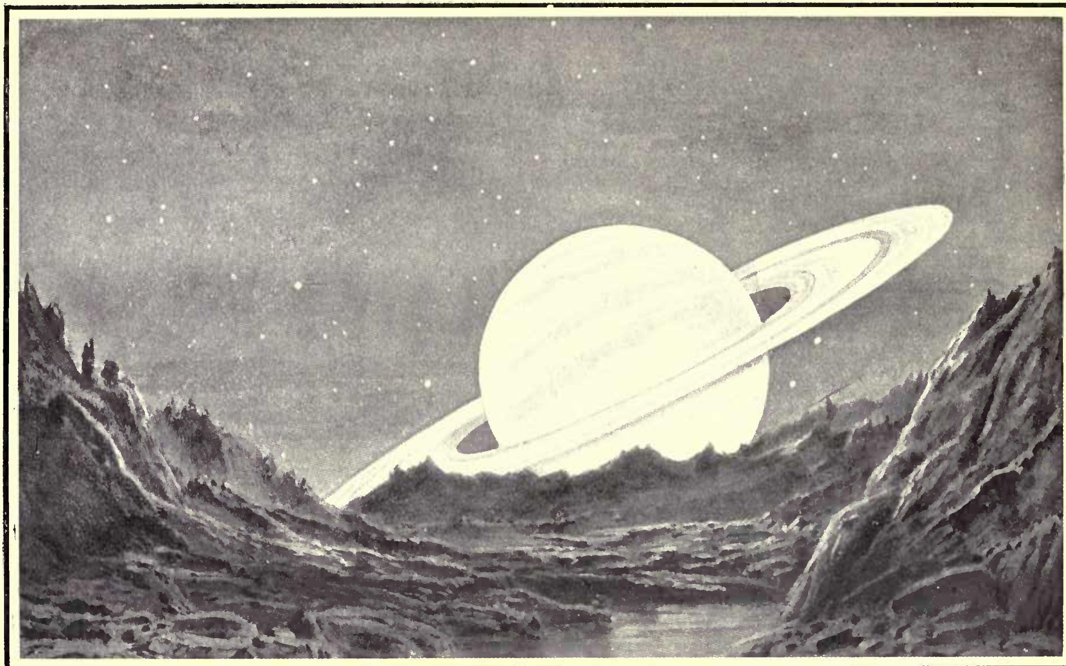
the ring system, which is very thin, directly in the line of vision, and thus see it edgewise. Galileo knew nothing of this, and he was astonished at the planet's change of shape. He was utterly cast down. Writing to his friend the ambassador of the Grand Duke of Tuscany, in the end of 1612, he said: "Were the appearances indeed illusion or fraud, with which the glasses have so long deceived me as well as many others to whom I have shown them? I do not know what to say in a case so surprising, so unlooked for and so novel. The shortness of the time, the unexpected nature of the event, the weakness of my understanding, and the fear of being mistaken have greatly confounded me." So much was Galileo disappointed at his failure to solve the problem, that he gave up observing Saturn altogether. It was left to a later astronomer, the Dutchman Huyghens, to demonstrate the true nature of the appearances. With the aid of telescopes much more powerful than those used by Galileo, he came to the conclusion that the planet was surrounded by a ring. But he was not absolutely certain, and he wished to test his theory so that there would be no possibility of mistake. In those days it was the custom of men of science to publish their discoveries to the world in the form of anagrams. That is to say, they wished to secure for themselves the right of discovery and at the same time have the opportunity of confirming their theories. Accordingly he jotted down a number of letters in chaotic form, and published them in an apparently senseless jumble. Huyghens was afraid that while testing his theory of the existence of a ring some other astronomers might make the discovery independently, and thus rob him of the honour. Therefore he published the following anagram in 1656—

"aaaaaaa, ccccc, d, eeeee, g, h, iiiiiii, llll, mm, nnnnnnnnn, oooo, pp, q, rr, s, tttt, uuuuu."

Three years later he arranged the letters in their natural order, having satisfied himself that his theory was correct. This made up the following Latin sentence—"Annulo cingitur tenui plano nusquam cohaerante ad eclipticum inclinato." Translated into English this reads—"The planet is surrounded by a slender flat ring inclined to the ecliptic and nowhere touching the body of the planet." Many years afterwards it was found that the ring was really composed of two rings. We now know of the existence of three; within the two bright rings there is a third known as the dusky ring. It was the last of the three to be discovered, and was first detected in 1850.

For many years it was supposed that the ring system was a solid whole—that the rings were flat planes. But it has been now proved that they are not solid, being made of innumerable small satellites or rather meteorites, and so close together are these minute bodies that they appear from this vast distance as a complete solid. They are in constant revolution round the planet. From Saturn it is probable that they appear as a continuous whole. Indeed, from the surface of the planet the ring-system must seem both magnificent and stupendous.

Let us imagine ourselves on the globe of Saturn on a journey from the pole to the equator, keeping a close watch on the Saturnian heavens. From the poles the rings are invisible. As we move equatorwards, the system gradually comes into view. As we advance, the rings rise higher and higher above the horizon. At the same time they diminish in breadth as we see them more and more foreshortened. At the equator they are exactly overhead, and we only see the interior edge of the system as a narrow arch extending right round the heavens. From a latitude of twenty-eight degrees on Saturn, says the



How Saturn would Appear from its Nearest Satellite

This imaginary illustration, from a drawing by Abbé Moreux, represents Saturn rising in the firmament of the nearest satellites. To these moons the ringed planet is a superb spectacle.

French writer Guillemin, "the ring-system is seen as an immense arch, interrupted by a large space at the summit. The sky is visible through the division which separates the two principal rings, and it again appears below the arch. The interruption at the summit is produced by the shadow cast by Saturn, and it is only distinguished from the sky by the absence of stars. It is possible, however, that this eclipsed portion of the rings may be sometimes rendered visible by the refraction of the solar rays by the atmosphere of the planet. . . . When we add to the strange beauty of the spectacle the presence of the satellites presenting different phases, some full, others new, others gibbous or crescent, an idea will be formed of the variety of aspect of the Saturnian nights."

This description applies only to the summer time of the particular hemisphere of the planet for which it is intended. In winter the ring-system reflects no light whatever to the planet. Not only do the rings give no light during the Saturnian winter, but they cut off the light of the Sun from the planet. They totally eclipse the Sun for long periods at a time. For fifteen years, half of the period of Saturn's revolution, the Sun is to the south of the rings, and for fifteen years to the north, but the shadow of the ring-system is so broad that the regions midway between pole and equator on Saturn have to suffer eclipses which last for more than five of our years at a time. Saturn is at a much greater distance from the Sun than the Earth, and receives much less sunlight; consequently it can ill afford to be deprived for long periods at a time of the little sunshine which is its due. Saturn therefore does not seem a very inviting dwelling-place for human beings.

In all probability, however, there are no inhabitants on

the planet. We learn this from a study of the globe itself. Saturn is the second largest planet in the solar system, and has a diameter of 74,000 miles. Suppose we represent the Earth by a pea; in proportion we may take an orange to represent Saturn. Its distance from the Sun is nearly nine hundred millions of miles, and it requires almost thirty years to revolve once round the central luminary. Like the Earth, Saturn rotates on its axis. This rotation is performed in Saturn's case in 10 hours 16 minutes—a much more rapid rate of rotation than that of our world, notwithstanding the greater size of the ringed planet.

The globe of Saturn, apart from the rings, is a striking spectacle—although not so striking as Jupiter—seen through a good telescope. The cloud belts do not show the same rapidity of change as do those of Jupiter. Still, changes are apparent to the careful observer. The only surface of Saturn which we can see is its atmosphere, which is so dense and cloud-laden that beyond it nothing is visible. On the Earth, and also on Mars and Venus, the atmospheric clouds are raised by the heat of the Sun. Venus, for instance, has a denser atmosphere than our world, probably because it is closer to the Sun. Mars, on the other hand, has a thinner atmosphere. But Saturn is at a much greater distance, and at that distance the heat of the Sun is so diminished in power that it could not be responsible for the existence of an atmosphere so much more cloud-laden than ours. The heat which raises the clouds comes not from the Sun, but from the planet itself. Like Jupiter, Saturn appears to be in a much earlier stage of development than the Earth. The oceans which will at some future date settle down on the planet's surface exist at present only in the form of masses

of cloud floating in the atmosphere. It is more than doubtful whether Saturn has any solid surface beneath the dense canopy of clouds. It may have a crust partly solidified, but subject to violent eruptions, such as seem to have been prevalent during the early stages of the life of our own world. Let us picture to ourselves what goes on beneath those cloud belts. A world in a state of chaos exists there—violent eruptions take place; boiling, seething masses of fire shoot through the partly solidified crust. It is a world of restless turmoil and sweltering heat. This view of the condition of Saturn is confirmed by the fact that while it is about seven hundred times larger than the Earth, it is only ninety times as heavy. Indeed, in proportion to its size, Saturn is the lightest of all the planets. It is only equal in weight to a globe of walnut wood of the same size. In fact, if we could imagine a great ocean large enough to hold the various planets, and if we could imagine the planets thrown one by one into that ocean, Saturn would actually float while all the others would sink. The extraordinary lightness of Saturn is explained by its condition of intense heat.

Thus we see that in two particulars Saturn is unique in the solar system. It is the lightest of all the planets, and it possesses a marvellous system of rings. But in another respect it is also unique. So far as we know, it possesses more satellites than any other planet. There are no fewer than ten of these little bodies owning it allegiance and circling round it in ceaseless revolution. In order of distance from the planet, the names of these little worlds are Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Themis, Japetus, and Phœbe. Of these, Titan is by far the largest. It was the earliest discovered, and was first seen by Huyghens during his

study of the planet. It is about three thousand miles in diameter, and equal in size to the planet Mercury. Indeed Titan is quite a little world in itself. The faintest, and probably the smallest, is Themis, which was discovered in 1905 by Professor W. H. Pickering of Harvard, by means of photography. So faint is the little moon that it is quite invisible by ordinary telescopic methods, and is only known by its image on the photographic plate.

The most remarkable member of the system of Saturn, however, is the little moon known as Phœbe, the most distant of the satellites. All the other nine moons revolve from west to east, the rings also revolve in that direction, the planet likewise rotates in that direction. But Phœbe revolves in the opposite direction—from east to west. Just imagine, if we had a number of moons and one of them revolved in the opposite direction from the others, how complicated and bewildering our evening skies would become.

The satellites have great diversities in their periods of revolution. Little Mimas, the closest to Saturn of the ten, is at a distance of 115,000 miles, and revolves in 22 hours 37 minutes. Phœbe requires sixteen months for its slow revolution round its primary. In the heavens Saturn, with its magnificent system of rings and its gorgeous retinue of moons, is a spectacle as majestic as it is unique. If any of its satellites be inhabited, these inhabitants will probably regard the planet as we regard the Sun—as light giver and heat giver; and with good reason will they look on Saturn as their Sun, as probably it gives out a certain amount of intense heat. Supposing either Saturn or its satellites were inhabited, the inhabitants would be hardly able to catch a glimpse of our Earth. Seen from Saturn, the Earth is a small insignificant point, lost in the light of the far-away luminary, the Sun.

CHAPTER XII

THE BOUNDARIES OF THE SOLAR SYSTEM

SATURN was the most distant world known to the ancients. They regarded its orbit as the boundary of the planetary system, and it was not until the year 1781 that astronomers learned that the solar system extended to a much greater distance than the orbit of Saturn. Of the two distant planets Uranus and Neptune little is known, but the story of their discovery is one of the most interesting chapters in the history of astronomy.

To the genius and skill of William Herschel we owe the discovery of the planet Uranus. The record of this discovery is so bound up with the life-story of the discoverer that it is impossible to separate them. That life-story[1] is a record of endless perseverance, boundless energy, and undying enthusiasm. The most striking of all discoveries, however, was nothing less than that of a new planet revolving beyond the orbit of Saturn—the first new member of the solar system discovered within the memory of man. On March 13, 1781, while observing the stars in the constellation Gemini, he, in his own words, "perceived one that appeared visibly larger than the rest." Comparing it with other stars in the vicinity, and "finding it to be so much larger than either of them, he suspected it to be a comet." For some time it was believed to be one of these objects, but when its orbit had

[1] See the chapter on the "Conquest of the Stars."

been calculated by mathematical astronomers it soon became apparent that, instead of revolving in a very long ellipse as most comets do, it moved in an orbit almost circular. There was no doubt therefore that the German musician had discovered not a comet, but a new planet, and had doubled by this discovery the diameter of the solar system.

The scientific world was amazed at the discovery. It had never even suspected that an unknown orb revolved beyond the orbit of Saturn. It was, however, even more surprising to find that Uranus had often been seen and catalogued as an ordinary star—no fewer, indeed, than seventeen times. Flamsteed, the first Astronomer Royal of England, observed Uranus four times in different positions, and did not notice the difference of place. A French astronomer, Le Monnier, narrowly escaped discovering the planet in 1769, and would certainly have done so but for the careless and slovenly way in which he jotted down his observations.

Herschel proposed to name the new planet "Georgium Sidus" (the Star of George), after his patron George the Third. This title naturally found no favour on the Continent. A French astronomer suggested the name Herschel after the discoverer himself, while Bode of Berlin suggested Uranus, in keeping with the custom of naming the planets after the Greek and Roman divinities. All these names were in use for a considerable time, but at length the name Uranus prevailed, and is now universally adopted.

The discovery of Uranus was a remarkable achievement, but it led to one still more remarkable—the detection of a planet still farther removed from the Sun. After Uranus had been duly recognised as a member

of the Sun's family of planets, its orbit was calculated. In making these calculations astronomers utilised the early observations of Uranus made by the observers who had failed to notice its difference from an ordinary star. The observations were far from useless, for although these observers had failed to make the discovery which was within their grasp, they had measured carefully the positions of their supposed star. This was all that mathematicians needed to enable them to calculate the planet's orbit with a further approach to accuracy. Bouvard, a French astronomer, published tables giving the planet's positions in the future. But as Uranus did not conform to the orbit which had been laid down for it, Bouvard concluded that there must be some mistake in the earlier observations. Accordingly in 1821 he rejected these altogether, and published a new series of tables, utilising only the observations made since Herschel's time. Again, however, the planet was not in the predicted place. The error was very minute, it is true; as the late Miss Clerke points out, "if the theoretical and the real Uranus had been placed side by side in the sky, they would have seemed to the sharpest eye to form a single body." In an exact science like astronomy, however, an error like this is intolerable, and is evidence of some flaw in the theory. Some astronomers began to doubt the universality of the law of gravitation on which all these calculations were founded, and to ask if the law did not break down at the boundaries of the solar system.

Gradually the idea dawned on astronomers that perhaps another planet, at a greater distance from the Sun, was attracting Uranus from the predicted path. The problem was, how could this be tested. It is no easy matter to search through thousands of stars along the zodiacal

constellations to find a planet: such a task would be impossible. The only hope of detecting the planet lay in calculating its position from its influence on Uranus. Here was a mighty problem involving great mathematical powers. One of the greatest calculators of the day resolved to grapple with the question, but he died before the discovery was made. Another astronomer intended to investigate the matter, but found it beyond his powers. At length two investigators in England and France respectively took up the question independently and quite unknown to each other. Adams, a student at the University of Cambridge, noted in his diary in 1841 his resolve to investigate "the irregularities in the motions of Uranus, which are as yet unaccounted for, in order to find whether they may be attributed to the action of an undiscovered planet beyond it; and, if possible, thence to determine the elements of its orbit approximately, which would lead probably to its discovery." In 1843, after taking his degree at Cambridge, he commenced his investigation, which occupied him for two years. On October 21, 1845, he called at Greenwich Observatory, and left a paper containing the elements, position, orbit, &c., of the supposed planet, and approximately fixing its position in the heavens—expecting that the Astronomer Royal of England, Sir George Airy, would institute a search for the body. Airy, however, was not particularly interested in this question; he was above all what may be called a practical astronomer, and he paid little attention to the paper which the young Cambridge graduate left for his consideration. Adams, too, did not seem particularly anxious to have a search instituted, and the result was that his paper remained in obscurity until it was too late. In 1845, Le Verrier, one of the rising astronomers of France,

also undertook to solve the problem, and he also assigned the position in the heavens of the disturbing planet in the constellation Aquarius. Sir George Airy happened to see one of the papers in which Le Verrier had published his conclusions. He was impressed by the fact that the two independent investigators had reached the same result, and accordingly he wrote to the director of the Observatory at Cambridge requesting him to search the region of the heavens to which Adams' calculations pointed. The Cambridge astronomer commenced a search, but he had no star-maps, and had to chart the region of the heavens before he could search for the planet. At length Le Verrier, having completed his investigations, wrote to Encke, director of the Berlin Observatory, requesting him to search for the planet. Encke at once set two of his assistants, D'Arrest and Galle, on the search, with the result that in a few hours, by the aid of some recently published star-maps, Galle perceived, almost exactly in the position indicated by Le Verrier, a strange star, which was soon identified as the disturber of the motions of Uranus.

Thus was the great discovery accomplished, and another planet added to the solar system. The name of the newly found celestial object was more easily settled than that of Herschel's planet. The following extract from the reminiscences of Sir Henry Holland, the well-known physician, tells us of the naming of this distant world. After referring to his visits to foreign Observatories, undertaken owing to his great interest in astronomy, he says: "That which most strongly clings to my memory is an evening I passed with Encke and Galle in the Observatory of Berlin, some ten or twelve days after the discovery of the planet on this very spot; and when

every night's observations of its motions had still an especial value in denoting the elements of its orbit. I had casually heard of the discovery at Bremen, and lost no time in hurrying on to Berlin. The night in question was one of floating clouds, gradually growing into cumuli, and hour after hour passed away without sight of the planet which had just come to our knowledge by so wonderful a method of predictive research. Frustrated in this main point, it was some consolation to stay and converse with Encke in his own Observatory, one signalised by so many discoveries, the stillness and darkness of the place broken only by the ticking of the astronomical clock, which as the unfailing interpreter of the celestial times and motions, has a sort of living existence to the astronomer. Among other things discussed while thus sitting together in a sort of tremulous impatience was the name to be given to the new planet. Encke told me he had thought of Vulcan, but deemed it right to remit the choice to Le Verrier, then supposed the sole indicator of the planet and its place in the heavens, adding that he expected Le Verrier's answer by the first post. Not an hour had elapsed before a knock at the door of the Observatory announced the letter expected. Encke read it aloud, and, coming to the passage where Le Verrier proposed the name of 'Neptune,' exclaimed '*So lass den namen Neptun sein.*' It was a midnight scene not easily to be forgotten. A royal baptism, with its long array of titles, would ill compare with this simple naming of the remote and solitary planet thus wonderfully discovered."

Thus closes the record of a remarkable discovery—perhaps the most remarkable ever made in astronomy. The discovery of Neptune was not only a magnificent attack on the secrets of Nature, but a glorious triumph

Unfounded Fear of the Chinese at the Great Comet of January, 1910

This plate shows an excited crowd endeavouring to "frighten away" the comet by means of bonfires and burning torches.

of the human intellect. The honour of the discovery is now given equally to Adams and Le Verrier, although for some time controversy raged as to which of the two deserved most glory. If Le Verrier's results were slightly more accurate than those of Adams, the latter investigator was earlier with his calculations. In this chapter much space has been given to the history of these two discoveries. In the case of the well-known planets, we know nothing of their discovery, but we have considerable knowledge of their physical condition. In the case of the distant worlds we know practically nothing of their physical condition, while the story of the two discoveries, the second the outcome of the first, forms one of the most fascinating chapters in the history of science.

Dusky bands, resembling those of Jupiter, were noticed on the disc of Uranus in 1883 by the late Professor Young. Some astronomers consider that the planet rotates on its axis in about ten hours, but this has not been confirmed by other observers. However, various facts tend to show that its period of rotation must be short. Uranus, so far as is known, is in a condition of great heat. The spectroscope has shown that free hydrogen exists in the Uranian atmosphere, and this indicates the existence of a temperature high enough to separate water into its constituent elements. Observations at the Lowell Observatory a few years ago indicated the existence in the planet's atmosphere of the element helium.

Uranus has four satellites, known as Ariel, Umbriel, Titania, and Oberon. Of these the two last named were discovered by Sir William Herschel in 1787. Ariel was glimpsed by the astronomer Lassell on 14th September 1847, and Umbriel by Otto Struve a few weeks later,

their existence being finally confirmed by Lassell's observations a few years later. The satellites are very faint. Ariel, the nearest satellite, revolves round Uranus in 2 days 12 hours, at a mean distance of 124,000 miles. Umbriel revolves in 4 days 3 hours, at a mean distance of 173,000 miles. Titania, at a mean distance of 285,000 miles, revolves in 8 days 16 hours; while Oberon, at a mean distance of 381,000 miles, requires 13 days 11 hours to circle round its primary. Nothing is known of the physical condition of these satellites. A remarkable fact connected with them is that they revolve almost at right angles to the plane of the ecliptic, in which most of the planets and satellites move. It is quite possible that there may be other satellites of Uranus yet undiscovered.

If little is known of Uranus, less is known of Neptune; the two worlds are about the same size, and seem to have many points in common. The spectrum of Neptune has been investigated by various observers, who have found it to resemble closely that of Uranus. In 1883, Mr. Maxwell Hall, an astronomer in Jamaica, noticed certain variations of brightness, which he believed indicated that the planet rotated on its axis in about 8 hours, but this observation has not been confirmed. Neptune has one satellite, so far as is known. It was discovered by Lassell on 10th October 1846—only a fortnight after the planet itself was detected. It is situated at a distance of 223,000 miles from its primary, round which it moves in 5 days 21 hours 8 minutes. Like the Uranian moons, its motion is retrograde. It must be very large to be visible at all at a distance so vast. Some astronomers consider that it is the largest satellite in the solar system. Probably it is over three thousand miles in diameter.

We have now described the outermost planet of the

solar system, revolving in solitary loneliness. But is the orbit of Neptune really the frontier of the Sun's domain? Are there planets beyond Neptune? Astronomical science has not yet answered these questions. The existence of one planet at least has been strongly suspected, and at the present time (1910), Professor W. H. Pickering is undertaking a search for a world beyond Neptune, the existence of which he believes to be indicated by its influence on the motion of certain comets. It may, however, be many years before such a planet, if it exists, is detected.

We have now come to the end of a description of the solar system, proceeding outwards from the Sun. But the planets and their satellites are not the only bodies in the solar system. There exists another class of celestial objects—the cometary and meteoric bodies. To the consideration of these the next few chapters will be devoted.

CHAPTER XIII

THE SUN'S FAMILY OF COMETS

OF all the celestial bodies, perhaps comets are the most remarkable and the most mysterious. They are totally unlike the planets; instead of being round solid globes, they seem to be diffused masses. Instead of revolving round the sun in orbits nearly circular, those comets which have been proved to belong to the solar system move in enormously long ellipses, and are only seen for a brief period when in the vicinity of the Sun and the Earth.

Among the ancients, and indeed in the Middle Ages, comets were a source of terror to mankind, and were regarded as terrible portents of wars, famines, deaths of kings, and other national calamities. A bright comet which appeared in 1066 was supposed to be a portent of the Norman Conquest of England. Another which was seen in 1456 was believed to be connected with the taking of Constantinople by the Turks. In the Middle Ages, it has been remarked, every comet "was believed to be a ball of fire flung from the right hand of an angry God," and this view was by no means confined to the ignorant. We find Martin Luther and John Knox firmly believing in the direful effects of comets on the Earth and its inhabitants. In the seventeenth century an illness among cats in Germany was actually ascribed to the appearance of a comet. In our time, thanks to the advance of science, we know that comets have no effect

whatever on the Earth, either baneful or beneficial. Consequently terror at brilliant comets has given way to wonder and admiration.

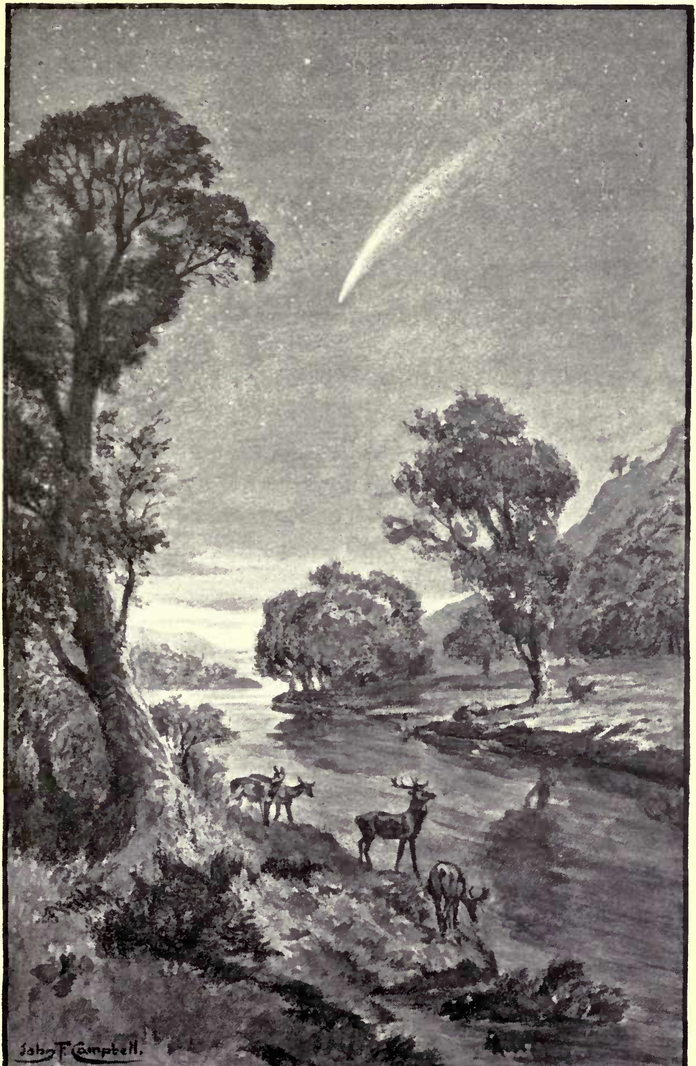
A bright comet may be said to consist of three parts—coma, nucleus, and tail—while faint comets only seen in telescopes generally lack the tail. To the ordinary star-gazer a comet is an object with a tail; but, as a matter of fact, comets with tails are far outnumbered by comets without tails—little comets which are only seen with the aid of the telescope, and which were consequently unknown to the ancient astronomers. Some comets not only lack a tail, but are also wanting in coma and appear like round diffused planetary discs. As was seen in previous chapters, the planet Uranus was at first believed by Herschel to be a telescopic comet, and Ceres, the first discovered of the asteroids, was also taken for a comet. When a comet is first seen in a powerful telescope, or first imprints its image on a photographic plate, it is merely a round faint nebulosity. As it approaches the Sun, if it is going to be a prominent comet, it develops the well-known tail or tails, for comets have been known with two, three, and as many as six tails.

Comets are of two kinds—those which belong to the solar system, and those which do not, and in this chapter attention is given to the former class. The scientific study of comets only began about the year 1680, when Sir Isaac Newton, in his investigation of them, demonstrated that they were, like the planetary bodies, subject to the action of the law of gravitation. Newton himself did not prove that any particular comet revolved round the Sun. This was reserved for his friend Halley, who in 1705 stated his conclusions on the subject.

Of all the comets which have been seen by the

Earth's inhabitants, the most famous is that which bears Halley's name. It was not the brightest seen, nor the most remarkable; but it was the first which was definitely proved to revolve round the Sun. There have been brighter comets, such as Donati's, and the great comet of 1811; but the chief interest in Halley's Comet lies in its regular returns at intervals of seventy-three or seventy-four years.

In the year 1682, while Newton was busily engaged in testing his law of gravitation, a bright comet made its appearance, and was attentively studied by the foremost astronomers of the day. Among these was Edmund Halley, the well-known Englishman, who became the second Astronomer Royal of England. It occurred to Halley that comets possibly revolved round the Sun in orbits similar to those of the planets, and that it would be useful to investigate as to whether a comet had been seen more than once. As Sir Robert Ball says: "At the expense of much labour, he laid down the paths pursued by twenty-four of these bodies which had appeared between 1337 and 1698. Amongst them he noticed three which followed tracks so closely resembling each other that he was led to conclude that the so-called three comets could only have been three different appearances of the same body." The first of these three comets had been seen in 1531, while the second was observed by Kepler in 1607, and the third was the bright comet studied by Halley himself in 1682. The astronomer also noticed that bright comets had been seen in 1456, seventy-five years before 1531, in 1380, and also in 1305, at intervals of about seventy-six years. After a careful study of the comet's orbit, and of the effect which Jupiter would have in retarding the return,



Donati's Comet, 1858

This comet is generally believed to have been the finest cometary spectacle of the last century.

Halley predicted that the comet would reappear in the end of 1758 or the beginning of 1759. He knew that he himself would be dead long before its return, and he wrote thus:—"If it should return according to our predictions, about the year 1758, impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman." Posterity has not refused to admit this fact, and the name of Halley has ever since been associated with the comet. The verification of his prophecy reflects a glory on his name which will cause it to live for ever among the greatest of astronomers.

As the year 1758 drew near, great excitement prevailed among men of science to see whether Halley's prediction would be fulfilled. The astronomer had been dead for sixteen years, but nevertheless interest in his prophecy was unabated. The French mathematician Clairaut, and two other mathematicians, undertook the task of calculating the exact date of the comet's return. The outcome of these researches was to show that the attraction of Saturn would delay the return of the comet by 100 days and that of Jupiter by 518 days. Men of science all over the world watched anxiously, and at last on Christmas Day, 1758, the comet was sighted by an amateur, a farmer in Saxony. The comet reached its perihelion, or point nearest to the Sun, on March 12, 1759, and then disappeared on its long journey. In 1835 the comet again reappeared, and on November 15, 1835, passed the point of its path closest to the Sun. Three able mathematical astronomers undertook to calculate the exact date of the planet's perihelion passage. Damoiseau, a Frenchman, fixed on November 4, 1835; Pontécoulant, another Frenchman, fixed on November 12; Rosenberger, a German calculator, taking account of the

attractions of all the principal planets, fixed on November 11. The perihelion passage actually took place on November 15—a proof of the remarkable accuracy of the three calculators. In 1835 the comet was first detected at Rome, and was particularly studied by Sir John Herschel, who, on May 5, 1836, caught the last glimpse of the comet with his giant telescope. From 1836 to 1873 the comet was on its journey outward to the most remote point of its orbit, beyond the pathway of Neptune. In 1873 it reached its aphelion, as this farthest point is called, and then commenced returning with increasing velocity to the regions of light and heat.

In November 1908, plates were exposed in the region of the heavens where it was calculated that the comet would appear, but it was not until September 1909 that it was actually discovered photographically by Dr. Max Wolf of Heidelberg. The comet in May 1910 was disappointing as a spectacular object to observers in Britain; but the public interest was unprecedented. Halley's was thus the first comet which was proved to revolve round the Sun in an elliptic orbit, and to be subject to the law of gravitation just as the planets are. Also, of all the known periodic comets, it is the one which has the longest period of revolution.

The next comet ascertained to be also periodic, and to be a member of the Sun's family, was an insignificant little object known as Encke's Comet. On November 26, 1818, Pons, a French astronomer who devoted much of his attention to the discovery of these objects, detected a small telescopic comet. The German astronomer Encke undertook to calculate the orbit of the comet, and found it to be probably identical with comets discovered by the French astronomer Mechain in 1786, by Caroline Herschel

in 1795, and by Thulis in 1805. Encke accordingly found that the time required for the comet to revolve round the Sun was three years and a half, and he calculated that the comet would pass its perihelion point on May 24, 1822. True to Encke's prediction, the comet returned, and the perihelion passage took place within three hours of the time which he predicted. As the late Miss Clerke has remarked: "The importance of this event will be better understood when it is remembered that it was only the second instance of the recognised return of a comet; and that it, moreover, establishes the existence of a new class of bodies distinguished as comets of short period."

The comet returned again in 1825, and has returned ever since at regular intervals. At its return in 1828, it was actually visible to the unaided eye as a star of the fifth magnitude. In 1838 Encke made a remarkable discovery in connection with his comet. He found that it returned to its perihelion point two and a half hours before the predicted time. He accordingly put forward the theory that this acceleration of the motion of the comet was due to the existence of what he called a "resisting medium" in the vicinity of the Sun, too rarefied to retard the motions of the planets, but quite dense enough to make the path of the comet smaller, and eventually to precipitate it on the Sun. This theory was held for a considerable time, but in 1868 the acceleration began to decrease, and accordingly the theory was abandoned. At its return in 1904, the comet was well observed, being comparatively bright. In 1908, however, it was very faint, and the only record of its return in that year was its image on a photographic plate.

Mr. G. F. Chambers, in his book "The Story of the

Comets," gives the number of known short-period comets as thirteen. The periods of revolution vary from over three years in the case of Encke's Comet to over thirteen in the case of Brorsen's. It would require considerable space to describe each of these objects individually. Only some of the more prominent can be mentioned here. In 1843, Faye, at the Paris Observatory, discovered a comet which was ascertained to revolve round the Sun in an elliptic orbit in over seven years. Its orbit is the least elliptic of all the short-period comets. It was last seen at its return in 1895, being missed when it reached its perihelion in 1903. In 1884, Dr. Max Wolf discovered, at Heidelberg, a telescopic comet which was proved to revolve round the Sun in six years and three-quarters. Before 1875, it is doubtful if the comet was a permanent member of our system, as in that year its orbit was completely changed by the great attractive power of Jupiter.

Another remarkable comet was detected in 1892 by Mr. Holmes, an English amateur. Of this comet Professor Barnard, who carefully studied it with the great telescope of the Lick Observatory, wrote as follows:—"From several points of view it was one of the most remarkable comets ever observed. At the time of discovery, it was distinctly visible to the naked eye as a slightly ill-defined star of the sixth magnitude. The remarkable fact that the comet had attained naked-eye visibility when discovered, coupled with the further fact that this region must have been repeatedly swept over by comet-seekers to within a few days of its discovery, shows that the comet must have rather suddenly attained its conspicuous visibility." The orbit of Holmes' Comet is almost circular.

Another well-known comet is that known as Brooks' Second Periodic Comet. It was detected in 1889, and returned again to perihelion in 1896. In 1903 it was again observed much fainter than before. Mr. Chambers remarks in connection with this comet: "The steady diminution in the brightness is so marked that it is hazardous to predict its future. At its last return it was only visible in some of our largest telescopes. It is due to return in 1910, and again in 1917. Shall we see it? Perhaps we shall; perhaps we shall not. But if we do see it on either of these two occasions, it will still be leading a threatened life, for in 1921 it will again approach very close to Jupiter, and very likely that may end its career; or if not, it will certainly lead to a serious transformation of its orbit."

Besides these comets of short period, there are six comets of long period: Westphal's, revolving round the Sun in sixty-seven years, and which is again due in 1913; Pons' Comet, revolving in seventy years, which returned in 1883, and is again due in 1955; Di Vico's, revolving in seventy-three years, which is due in 1919; Olbers', revolving in seventy-four years, which, first seen in 1815, returned in 1887, and is again due in 1960; Brorsen's, with a period of almost seventy-five years, which is due in 1922; and finally, Halley's, already referred to.

Thus it is known that the solar system contains certainly thirteen comets of short period, and six of long period. Besides, it is believed that fourteen other comets are also periodic. Their periods range from five to nine years, but they have not been proved beyond a doubt to belong to the solar system. Besides these periodic comets there are three, Lexell's Comet, Di Vico's Comet, and Biela's Comet, which were once periodic, and

have now either ceased to exist or have been deflected into new paths.

The first named was discovered by Messier, a famous discoverer of comets, on June 14, 1770. An orbit was calculated for it by a Russian mathematician named Lexell, who assigned to it a period of five and a half years. It was, however, never seen again. Lexell found that in 1707 the comet had passed very close to Jupiter, which had completely altered its path; and accordingly he made another calculation, to the effect that the comet should be seen in 1781, but again he was doomed to disappointment. He finally concluded that, in 1779, Jupiter had again altered the comet's path by its enormous attraction when the flimsy cometary body again passed near to the giant planet. Lexell's Comet has never since been seen.

In 1844 a comet was detected at Rome by Di Vico, and an orbit was assigned of 1993 days. The comet, however, was never seen again. The most remarkable case of all was that of Biela's Comet, which, after being known for years as a member of the Sun's comet family, disappeared in 1852, and was not again seen. In a future chapter this comet, which is the key to our knowledge of the nature of these bodies, will be fully discussed.

The comets above mentioned are those which belong to the Sun's system. The great majority of comets with which the next chapter deals have not been proved to belong to our system, and many of them seem to be only visitors from the depths of space.

CHAPTER XIV

THE MESSENGERS OF SPACE

THE previous chapter dealt with those comets which are known to belong to the solar system, and which are thus always subject to the influence of the Sun. In the present chapter attention is directed to the large comets, which are either visitors to the solar system from the depths of space or which, if they do revolve round the Sun, move out to distances so enormous that we cannot with certainty pronounce them to be members of the Sun's family. Many of the most famous comets which have ever appeared belong to these two classes.

Some of the comets contained in the second class probably belong to the solar system, but their periods are so long that astronomers do not know whether or not they will ever return. For instance, the second comet of 1824 has been calculated to have a period of millions of years, the first comet of 1863 has been said to revolve in nearly two million years, the comet of 1680 in over fifteen thousand years, and so on; but no one can implicitly trust these estimates, as much uncertainty surrounds them. Such comets might, in their long journey in space, be attracted from their paths by dark stars or meteor streams, and would thus be lost for ever to the solar system. They cannot be regarded as permanent members of the solar system.

Most of the really grand comets which have been seen—with the exception of Halley's Comet at its appear-

ances—have belonged to either of these two classes. The comet of 1264, a magnificent object which was supposed to have been identical with the comet of 1556, was expected on this supposition to return about 1858. But it was not seen again, and consequently it is doubtful if the two comets were really identical. In 1264 popular superstition fixed on the comet as a presage of the death of Pope Urban IV.

A remarkable comet, known as De Chéseaux's Comet, appeared in 1744. It had no fewer than six tails. De Chéseaux, the discoverer, has left a very detailed description of the object. He wrote as follows:—"The sky was quite overcast from the first to the seventh of March, but on the last-named day the clouds became broken and gave us some hope of seeing the comet's tail. I prepared myself for seeing over again just about what I had seen during the closing days of February. At four o'clock on the morning of March 8th, I went downstairs with a friend into the garden, with the east facing us. This friend, walking in front of me, startled me by saying that instead of two tails there were five. I hardly believed him, but after having passed from behind several buildings which had partly concealed the eastern horizon from me, I did indeed see five tails. . . . Besides these five tails, there was a sixth." This was probably one of the most remarkable comets ever witnessed.

The great comet of 1811 was in many ways unique. Discovered on 26th March 1811, it was last seen on August 17, 1812, nearly seventeen months later. The tail, when seen at its best in the middle of October, stretched into space for the distance of a hundred million miles, while its breadth was fifteen millions. Measurements made by Herschel indicated that the diameter of

the nucleus of the comet was 428 miles. A famous German astronomer calculated its orbit, and estimated that its greatest distance is fourteen times that of Neptune, and its period over three thousand years.

Another magnificent comet appeared in 1843. This was described as "a grand and wonderful sight for the extraordinary distance of one-third of the heavens, the nucleus being perhaps about the size of the planet Venus." This remarkable comet, one of the brightest which has ever been seen, was detected in the end of February 1843, in the southern hemisphere. After the middle of March the comet became visible in the northern hemisphere. The remarkable feature about the comet of 1843 was its near approach to the Sun. Its central portion was within 78,000 miles of the orb of day, so that only a little over thirty thousand miles separated the surface of the Sun and the comet. The result of this near approach was that the comet whirled past its perihelion point at the amazing rate of 366 miles per second. In two hours and eleven minutes it described half of the curvature of its oval-shaped orbit, while, as one astronomical writer has pointed out, "in travelling over the remaining half, many hundreds of sluggish years will doubtless be consumed." In many ways the comet of 1843 was a remarkable object. Its tail streamed into space for two hundred millions of miles.

The next brilliant comet was detected by Donati at Florence on June 2, 1858, as a little round nebulous mass, very faint, in the constellation Leo, and is considered by most astronomers to have been the grandest comet of the nineteenth century. At first no one suspected that the faint little telescopic object would develop into so magnificent a stellar spectacle as the comet of Donati. In the middle of July a nucleus de-

veloped. In the middle of August a tail began to make its appearance, and by the beginning of September it was visible to the unaided eye. By the twelfth of that month, the nucleus of the comet shone with a brilliance equal to that of the Pole Star. From this date a magnificent celestial spectacle was assured. Occupying a favourable position in the northern heavens, it was in a most famous position for observation. "This comet," as Mr. G. F. Chambers has pointed out, "has not often been equalled in the intense brilliance of its nucleus, and the unusual and, so to speak, artistic configuration of its tail, which features the absence of the Moon in the early part of October, enabled spectators to view to the very best advantage. The passage of the comet in front of Arcturus on October 5th will ever remain treasured in the memory of those who saw it." The late Miss Clerke confirms this estimate; she says: "The most striking view was presented on October 5th, when the brilliant star Arcturus became involved in the brightest part of the tail, and during many hours contributed, its lustre undiminished by the interposed nebulous screen, to heighten the grandeur of the most majestic celestial spectacle of which living memories retain the impress."

The comet was followed by astronomers until March 4, 1859, when it disappeared from the view of the largest telescopes then in existence. Various estimates have been made of the period, such as 1879 years and 2040 years and 2138 years. One calculation suggested that Donati's Comet was identical with a famous comet which appeared in 146 B.C. and is mentioned in the Chinese annals. But the periods calculated are very uncertain. Estimates, probably correct, have been made of the dimensions of the nucleus and tail of the comet. The tail was 14,000,000 miles

long on 30th August, and seems to have reached its maximum length on 10th October, when it streamed outwards into space for 51,000,000 miles. On the same day the nucleus was estimated as 630 miles in diameter. The comet was carefully studied by astronomers on both sides of the Atlantic. Good weather prevailed during its nearest approach to the earth, and consequently it was thoroughly and exhaustively studied.

Three years later another brilliant object, perhaps even more remarkable than Donati's Comet, became visible to the Earth's inhabitants. It was discovered on May 13, 1861, in New South Wales, and on 11th June passed its perihelion point. On 29th June it became visible in the northern hemisphere. The following description was given by Sir John Herschel, who observed it from Hawkhurst, in Kent: "The comet, which was first observed here on Saturday night, June 29th, by a resident in the village of Hawkhurst, became conspicuously visible on the 30th, when I first observed it. It then far exceeded in brightness any comet I have before observed, those of 1811 and the recent splendid one not excepted. Its total light certainly far surpassed that of any fixed star or planet, except perhaps Venus at its maximum."

The remarkable fact about the great comet was that on the night of 30th June, the Earth and Moon passed through its tail. The comet was at the time between the Earth and the Sun, fourteen millions of miles from our planet, while its tail stretched outwards for fifteen millions of miles. The passage of the Earth through this tail was almost imperceptible. The vast majority of persons never knew that such an event had taken place, and even the astronomers noted only a singular phosphorescence in the sky. Lowe, a meteorologist of the day, remarked

that the sky had a yellow auroral aspect, and that the Sun gave but feeble light although the sky was cloudless, and at seven o'clock in the evening, although it was the midsummer season, artificial lights had to be used. The fact that our world passed through its tail and that the inhabitants were unaware of the fact, is the strongest proof of the harmlessness of this large comet.

The comet of 1874 discovered by a French astronomer named Coggia, at Marseilles, on 17th April 1874, and since known by his name, was much less brilliant than its predecessor in 1861, but nevertheless was a fine celestial spectacle. In July it became visible to the unaided eye. On the 21st of that month it was at its nearest point to the Earth, a distance of nine millions of miles. Various estimates have been made of the period in which the comet revolves. One calculation assigned a period of 5711 years, and another a period of 10,455 years.

The comet of 1880, seen in the southern hemisphere only, was one of the most remarkable cometary bodies. In appearance it was very similar to the great comet of 1843, and when its orbit was calculated it was found to revolve in a path almost identical with that famous body. Three of the most distinguished calculators investigated the comet's motions independently, and each found the path of the two bodies almost identical. Two years later another great comet was discovered by the director of the Observatory at Rio de Janeiro. It soon became a magnificent object in the southern hemisphere. Sir David Gill, who observed it from the Cape Observatory, remarked that the comet "showed an astonishing brilliancy as it rose behind the mountains to the east of Table Bay, and seemed in no way diminished in brightness when the Sun rose a few minutes afterwards. It was only necessary

to shade the eye from direct sunlight with the hand at arm's length to see the comet with its brilliant white nucleus and dense white sharply bordered tail of quite half a degree in length." The comet passed between the Earth and the Sun on the 17th September, and on the following day was visible in full sunlight close to the orb of day. In Spain it was seen through a passing cloud when very close to the Sun.

The most remarkable feature of this great comet was the fact that its orbit showed a remarkable resemblance to the great comets of 1843 and 1880. Astronomers were amazed at this discovery. It was at least possible that the comet of 1880 was a return of that of 1843; but for an enormous comet to return in only two years was unthinkable. As the late Miss Clerke remarked, "A comet which at a single passage through the Sun's atmosphere encountered sufficient resistance to shorten its period from thirty-seven to two years and eight months must in the immediate future be brought to rest on his surface." The great comet was kept under observation for about six months, but before it disappeared the opinion was widespread that it was not a return of the comets of 1843 and 1880. In 1887 another comet was discovered with an orbit also similar. Now the only explanation of the identity of these orbits is that each of these comets were fragments of a larger cometary body which, revolving in the same orbit, had been gradually disrupted into a number of different comets—the comets of 1668, 1843, 1880, 1882, 1887, and probably also another comet, seen in 1882. This is proof that comets, unlike the planets, are not lasting—that they are liable to be dissipated into space. This much may be gathered from a study of the movements and orbits of comets.

Much more remarkable, however, is the information gained by a study of their physical conditions.

After 1882 no very brilliant comet was visible in the northern hemisphere, although in 1901 another bright southern comet was observed. In 1902, Perrine's Comet was faintly visible to the unaided eye, but too faintly to attract popular attention. The appearance of the great daylight comet of 1910 came therefore as a pleasant surprise not only to astronomers, but also to the general public. On January 15, 1910, the Johannesburg newspaper, *The Leader*, informed Mr. Innes, director of the Transvaal Observatory, that they had received the following telegram from the station-master at the railway station at Kopjes, in the Orange Colony: "Halley's Comet was seen by Fireman Bourke, Driver Tucker, and Guard Marais at 4.45 rising in front of the sun. It was visible for about twenty minutes."

"The railway employees had seen the brilliant object in the sunrise before the astronomers saw it, and they thought it was Halley's Comet, which was due to return at that time. As soon as the comet was observed, however, it was seen that it could not be Halley's. Warned by this message from the station-master, we kept watch on the next morning, but it was cloudy. This morning (January 17) was also cloudy, but there was a break just above the place of sunrise. At 5.29 standard time the comet was seen."

In a later statement Mr. Innes said: "The earliest date on which this comet was seen in South Africa appears to be on Thursday, January 12, at 14 hours 25 minutes Greenwich meantime, by some workmen at the Transvaal Premier Diamond Mine. A letter from Cullinan, dated January 16, informed me that on that date and also on Friday morning several workmen observed the comet."

The comet soon passed the Sun, and became visible

in the evening skies—a magnificent object, which attracted much attention; and had it not been for the unfavourable weather in Great Britain at the time, a good deal more would have been seen of it. On the clear evenings the comet was observed and admired by the average man and closely studied by the astronomer. The comet was observed by the present writer at Balerno, Mid-Lothian, on January 22 and 29, observations on other dates being impossible owing to the unfavourable weather. Seen in a two-inch refractor on January 29, the nucleus was very bright and well defined, while the head presented a resemblance to drawings of Coggia's Comet of 1874.

Even at the large Observatories it was difficult to get good photographs, owing to its position in the western sky so close to the sunset twilight. The spectrum of the comet was observed by Professor Frost, director of the Yerkes Observatory, on January 24, when the bright lines of sodium characteristic of many comets were noted. The element cyanogen was also detected. The spectroscopic observations indicated that on January 27 the comet was receding from the Earth with a considerable velocity. This agrees with its very rapid diminution in brightness. On January 29 it was well seen; a few days later it was practically invisible.

The lines addressed to the "Stranger of Heaven," the great comet of 1811, by the "Ettrick Shepherd," seemed specially appropriate to the comet of 1910:—

"Stranger of heaven, I bid thee hail!
Shred from the pall of glory riven,
That flashest in celestial gale
Broad pennon of the King of Heaven.

Whate'er portends thy front of fire
And streaming locks, so lovely pale,
Or peace to man or judgment dire,
Stranger of Heaven, Ibid thee hail!"

CHAPTER XV

THE NATURE OF COMETS

IN the two previous chapters mention was made of the two principal classes of comets—comets which have been proved to belong to the solar system, and those comets which either belong to our system, revolving in uncertain periods, or only pay a fleeting visit to the planetary regions, dashing away again into space. Although these two classes differ in many respects, they only differ in regard to their orbits. That is to say, all comets, whether they belong to the solar system or not, are alike in their constitution and nature; and in this chapter an attempt will be made to explain the complicated phenomena connected with them.

The most striking feature about a bright comet is its tail. As remarked in a previous chapter, telescopic comets are often devoid of tails, but all bright comets are distinguished by these appendages, and consequently, to the average man and the casual star-gazer, a comet is only of interest if it possesses a tail. One of the most notable things about the tails of comets is that they are always pointed away from the Sun. If the comet is approaching the Sun, the tail follows the head. If it is receding from the Sun, the head follows the tail. This is a remarkable fact, which shows that comets lack the stability which characterises the planets. For many years this fact puzzled astronomers, and it was not until the beginning of last century that any progress was made

From a photograph by Dr. Max Wolf

MOREHOUSE'S COMET, 1908

This comet attracted a great deal of attention, although only a telescopic object. The agitation in the matter forming the tail will be noticed in the photograph.

towards an explanation. The astronomer Olbers, of Bremen, well known for his discovery of the asteroids, explained the tails of comets very simply. The Sun not only attracts comets and planets to itself, but its light exercises a repulsive power on minute particles, which are thus driven off in a direction opposite to the Sun. This theory was very fully elaborated by a famous Russian astronomer, the late Professor Brédikhine. Brédikhine's researches led him to divide the tails of comets into three types. The first of these consists of long straight tails, pointed directly away from the Sun, represented by the tails of the comets of 1811, 1843, and 1861. In the second of these types, represented by those comets bearing the names of Donati and Coggia, the tails, although on the whole pointed away from the Sun, are considerably curved. The tails of the third type have been described as "short, strongly bent, brush-like emanations," which in bright comets "seem to be only found in combination with tails of the higher classes." He showed that, probably, tails of the first types are formed of hydrogen, those of the second of hydrocarbon, and those of the third of iron, with a mixture of sodium and some other elements.

On the whole, this theory is considered satisfactory. The question, however, presents itself,—What is this remarkable repulsive force? There seems to be a general agreement among the scientists that the force is electrical. It only affects the very smallest and most insignificant particles of matter, and this explains why the planets and solid bodies are not affected by the force. It has also been suggested that the repelling force may be due to what is called "light pressure," the action of rays of light on very minute particles of matter.

So much has been learned of the nature of comets by

theory. Most of our knowledge of these objects, however, is due to direct observation. The invention of the spectroscope, about the middle of the nineteenth century, referred to in a previous chapter, resulted in a considerable increase of our knowledge of comets and cometary phenomena. It was shown early in the history of this line of research, by Donati and others, that the light of comets is partly inherent and partly reflected. The late Sir William Huggins, the late Dr. Copeland, and others, ascertained the existence in the heads of comets of hydrocarbon gas, and this has been since confirmed by other observers. These observations, of course, give support to Brédikhine's theory of comets' tails. In 1882 this theory was still further confirmed by observations which the late Dr. Copeland and others made of Wells' Comet of that year. On May 27th, Copeland ascertained the existence of sodium in the comet. This was the first occasion on which that element was recognised in one of these bodies. The same astronomer also recognised sodium in the great comet of 1882.

A comet which contributed materially to our knowledge of cometary phenomena was that discovered on September 1, 1908, by Morehouse, an American astronomer. Observations on this object revealed the presence of the poisonous gas, cyanogen, which WERE ~~was~~ indeed the most prominent ~~element~~
$2 N_2$ in the comet, and which dominated its spectrum. Other remarkable disclosures were made by this comet. A large number of photographs were taken at the Goodsell Observatory, Minnesota. Professor H. C. Wilson, of that institution, remarks as follows on this comet: "While the observer was guiding the telescope for these photographs, the portion of the comet's tail which was in the field of the guiding telescope grew visibly fainter, and appeared to

detach itself from the head. The two photographs taken with the six-inch camera show that this appearance was real, and that the bright part of the tail was actually detached from the head of the comet and was moving outward." On October 15, a bend became apparent in the main tail, which photographs showed to be travelling rapidly from the head. "This outward motion," says one observer, "was also traceable in the case of several knots of brightness in the tail."

Morehouse's was not the only comet which was observed to break up. The great comet of 1882 was also seen to throw off portions of its mass. A German astronomer noted on 5th and 7th October of that year two centres of condensations in the comet, while on the 9th of the same month Schmidt detected a little nebulous object close to the comet, which had been apparently thrown off. Professor Barnard, some days later, glimpsed six or eight little cometary masses separate from the comet. Another instance of cometary disruption was afforded by Brooks' Second Periodic Comet, discovered in 1889. About a month after its discovery, it was seen to have thrown off four fragments. In his interesting work on comets, Mr. Chambers writes as follows:—"Two of these were very faint and soon disappeared, but the other two brighter ones were miniatures of the main body, each having a nucleus and a tail. For a while they moved away from their primary. In three weeks the nearer companion ceased to recede; it then expanded and finally disappeared. The fainter companion continued to recede until it had become, a month from discovery, brighter than the parent comet. In another month it began to approach its parent, its head swelling and becoming faint, the tail disappearing."

It is probable that astronomers have learned more of the constitution and nature of comets from one small member of the Sun's family, than from all the other comets—periodic and non-periodic—put together. On February 27, 1826, Wilhelm von Biela, an amateur astronomer at Josephstadt, in Bohemia, detected a faint comet which was independently noticed ten days later by a French observer, Gambart, at Marseilles. When its orbit was calculated, it was found to be identical with those of comets which appeared in 1772 and 1805. The comet turned out to be a periodic one, revolving round the Sun in a period of between six and seven years. Its return was predicted for 1832, and, true to calculation, it reappeared in that year. Its reappearance was made the occasion of a "comet scare." Certain calculations were made which seemed to show that portions of the comet would sweep over part of the Earth's orbit. This statement gave rise to a dread lest the comet should strike the Earth and our world be destroyed. A panic ensued among the ignorant, especially in Paris, and the popular excitement was not cooled until the director of the Paris Observatory announced that the Earth and the comet would at no time approach within fifty million miles of each other. The comet was not seen in 1839, owing to its unfavourable position in the heavens, but on November 28, 1846, it was re-discovered. In less than a month it was seen to be pear-shaped, and on December 29 and early in January, it was found that the comet had actually separated into two distinct portions. All over the world astronomers observed the comet with amazement, for this was the first occasion within the memory of man on which a comet was seen to divide into two portions. The comet again returned in 1852. The

companion comet was again seen, but at a much greater distance. It was now a million and a quarter miles from its primary, eight times its distance in 1846. In 1859 the comet was not observed, but this was not considered remarkable, as it was in that year unfavourably placed for observation. However, much interest was displayed at its return in 1866, at which date it was expected to be very favourably placed. An active search was instituted, but neither Biela's Comet nor its little companion was seen. The comet was obviously lost, and astronomers gave up hope of ever seeing it again.

But an extraordinary thing happened. The comet was again due to appear in 1872. It was not visible, but when the Earth crossed its path, on the night of November 27, there was a magnificent shower of shooting stars. Beginning shortly after sunset, the "rain of fire," as one observer called the display, lasted until eleven o'clock. Four hundred meteors were counted in a minute and a half; and some magnificent fireballs equal in size to the apparent diameter of the Moon were observed. The Earth had not collided with Biela's comet, but it was ploughing its way through the wreckage and *débris* into which the comet had dissolved.

A German astronomer, Klinkerfues, observing at Göttingen, was impressed with the idea that Biela's Comet, or at least a portion of it, might still be visible, and concluded that if it were to be seen at all, it would be in the southern hemisphere, in the opposite region of the heavens from the point from which the meteors had radiated. Accordingly, convinced that the meteors represented the shattered *débris* of the comet, and believing that other portions of it might still be in existence, he telegraphed to Pogson, the astronomer at Madras, the

following message: "Biela touched Earth November 27, search near Theta Centauri." Pogson promptly turned his telescope to that portion of the sky, and glimpsed on December 2, and again on the following evening, a very faint object, which he at first took for Biela's Comet or its companion. It was shown, however, that it could not have been either, but was probably another fragment which was detached at an earlier date. The orbit of

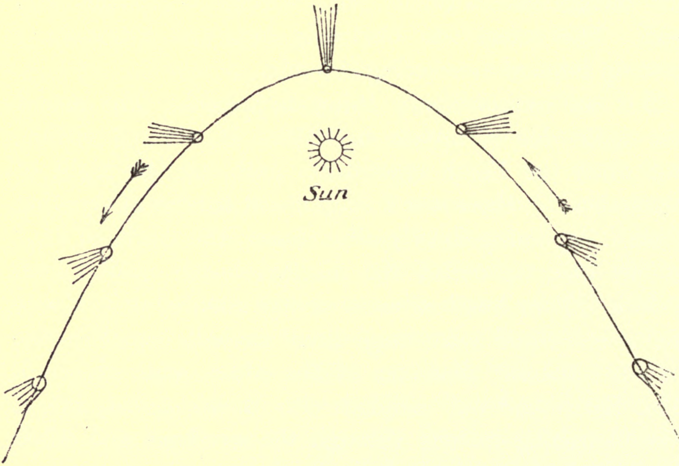


FIG. 5.—Showing how the Tail of a Comet is directed away from the Sun.

Biela's Comet was thus shown to be identical with the meteoric shower known as the Andromedids, and another fine shower was observed in 1885, when the Earth again crossed the path of the lost comet.

Biela's Comet therefore no longer exists; it has been dissolved into fragments; and with some of these fragments our planet collided on November 27, 1872, with the result that a display of celestial fireworks took place

A Shower of Meteors

A meteoric shower is one of the grandest of astronomical spectacles. Beginning with a display of one or two, then tens, then hundreds, it culminates in a "rain of fire." Such spectacles were witnessed in 1833, 1866, and 1872. The meteors all diverge from a common "radiant point."

which has seldom been surpassed. Thus we see that comets die, as Kepler said three centuries ago. Unlike the planets, they are not lasting, but break up into small particles of matter, which, when they enter our Earth's atmosphere, become ignited with the friction of the atmosphere and appear in the form of shooting stars.

To sum up, we know that comets are bodies of extreme tenuity. Stars are usually to be seen shining through them undimmed, and although they are of enormous bulk they have practically no weight. That is to say, they exercise no disturbing influences on the motions of the planets. In all these points comets differ from planets. And as already mentioned, there is another important point of difference. Although nothing in the changing Universe can be called eternal, the Sun and planets are certainly lasting bodies, but comets are not lasting. Even in the short period of man's life, comets have been seen to break up and disappear.

An admirable summary of our knowledge of comets is given by Mr. E. W. Maunder as follows :—" Though the bulk of comets is huge, they contain extraordinarily little substance. Their heads must contain some solid matter, but it is probably in the form of a loose aggregation of stones enveloped in vaporous material. There is some reason to suppose that comets are apt to shed some of these stones as they travel along their paths, for the orbits of the meteors that cause our greatest star showers are coincident with the paths of comets that have been observed. But it is not only by shedding its loose stones that a comet diminishes its bulk ; it also loses through its tail. As the comet gets close to the Sun, its head becomes heated and throws off concentric envelopes, much of which consists of matter in an extremely fine state of

division." Mr. Maunder goes on to show that for a particle of matter less than the one-twenty-five-thousandth part of an inch in diameter, the repulsive force of the Sun's light is greater than the attractive force of the central orb itself. "Particles in the outer envelope of the comet below this size will be driven away in a continuous stream, and will form that thin luminous fog which we see as the comet's tail."

Thus comets lose in bulk and mass through their heads and their tails. Of the subsequent history of the "luminous fog" driven off by the repelling power we know nothing, but of the loose stones shed by the head we know a great deal. To a consideration of these loose stones the next chapter will be devoted.

CHAPTER XVI

THE SHOOTING STARS

SCARCELY a night passes without the recurrence of a celestial phenomenon familiar to the most casual star-gazer. As Flammarion puts it in his picturesque language: "Sometimes when night has silently spread the immensity of her wings above the weary earth, a shining speck is seen to detach itself in the shades of evening, from the starry vault, shooting brightly through the constellations to lose itself in the infinitude of space." These "shining specks" are known variously as shooting stars, falling stars, and meteors. The latter term is the most scientifically accurate, because the "shining specks" are not stars. While the so-called "fixed stars" are huge globes, some exceeding the Sun in size at enormous distances from the Earth, the shooting stars are merely little stones and particles of matter a few miles above the surface of our planet. It must always be borne in mind, therefore, that the titles "shooting stars" and "falling stars" are incorrect, and that it is more accurate to refer to these objects as meteors. Scarcely a night passes without one or more of these meteors being seen. During the day, too, there are probably as many entering our atmosphere and flashing across the sky as at night; but owing to the sunlight they are unobserved. It has been calculated that every twenty-four hours the dust of four hundred million meteors falls to the surface of the Earth.

On most evenings meteors are observed in twos or threes. On some evenings more are to be seen than on others. On some occasions, however, these meteors are to be seen not in twos or threes, but in dense showers. In 1799, for instance, a bright shower of meteors was observed in South America by the famous Humboldt. On the night of November 12–13, 1833, there was observed perhaps the finest display of shooting stars ever witnessed by man. It was best seen in North America, and during the maximum it was quite impossible to count the number of meteors which flashed across the sky. It was estimated that their frequency was about half that of snowflakes in an ordinary snowstorm. It was calculated in fact that no fewer than 240,000 meteors were visible. Observations made on that memorable occasion showed that the paths of all the meteors traced backwards in the sky, intersected at a point in the constellation Leo. That is to say, the meteors radiated from a point in that star group. Hence this point was called the radiant point, and the star shower was called the Leonid display. On the occasion of this great display, the meteors struck terror into the hearts of the ignorant, especially the negroes on the plantations in the Southern States, who believed the end of the world to be at hand.

The fact that thirty-four years had elapsed since the magnificent star shower, led astronomers to expect another display about 1866 or 1867. An American astronomer, the late Professor H. A. Newton, undertook a search through the ancient records to see if he could find traces of star showers at intervals of thirty-three or thirty-four years. His search was successful, and he predicted a star shower on the evening of November 13 and morning of November 14, 1866. At the same time it was noted

A FIREBALL OR BOLIDE

These objects, known as bolides or fireballs, and the larger ones as aerolites, are occasionally visible, and form superb and celestial spectacles.

that meteors were to be seen yearly in varying quantities radiating from the same point in Leo.

Professor Newton's prediction was fulfilled. On the evening of November 13, there was a magnificent display of meteors—inferior, it is true, to that of 1833, but still magnificent. In his book, "In Starry Realms," Sir Robert Ball has given an excellent account of this fall of meteors, which he observed from Lord Rosse's Observatory, Birr Castle, Ireland, where he was at the time employed as astronomer to that nobleman. "The memorable night," says Sir Robert Ball, "was a very fine one; the Moon was absent, a very important consideration in regard to the effectiveness of the display. The stars shone out clearly, and I was diligently examining some faint nebulæ in the eyepiece of the great telescope, when a sudden exclamation from the attendant caused me to look up from the eyepiece, just in time to catch a glimpse of a fine shooting star, which, like a great sky-rocket, but without its accompanying noise, shot across the sky over our heads. About this time I was joined at the telescope by Lord Oxmantown (afterwards Earl of Rosse), and we resumed our observations of the nebulæ, but a grander spectacle soon diverted our attention from these faint objects. The great shooting star which had just appeared was merely the herald announcing the advent of a mighty host. At first the meteors came singly, and then, as the hours wore on, they arrrived in twos and in threes, in dozens, in scores and in hundreds. Our work at the telescope was forsaken; we went to the top of the castellated walls of the great telescope, and abandoned ourselves to the enjoyment of the gorgeous spectacle. To number the meteors baffled all our arithmetic; while we strove to count on the one side, many of them hurried

by on the other. The vivid brilliance of the meteors was sharply contrasted with the silence of their flight."

In 1867, another shower, much feebler than that of 1866, was seen, and as the years passed on the display became fainter, until the number of meteors seen on the particular night in November was normal. A display was predicted for 1899, in accordance with the thirty-three year period, but, to the great surprise and disappointment of astronomers, nothing was seen. In 1900 there was no better success. In November 1901 there was a fairly good shower observed in America, but vastly inferior to those of 1833 and 1866. Finally, in 1904 there was a fairly good display visible in Scotland. The writer observed the display at Balerno, in Mid-Lothian, and noted a considerable number of bright meteors. The shooting stars were not numerous, but they were brilliant, and, in short, the display was much above the normal. Since 1904, the November meteors have been few, about the usual number being observed.

There is another well-known shower of meteors. This is the Perseids, so called from the fact that the meteors appear to radiate from the constellation Perseus. These are to be seen in varying numbers, between the 9th and 11th of August every year. Unlike the Leonids, they have no well-defined period of greatest number and brilliance. Other two important showers are known, the Lyrids, seen in April, which appear to radiate from Lyra, and the Andromedids, which are to be seen towards the end of November. Many minor showers are known, but they are too faint and insignificant to attract general attention. When it was found that the Leonid meteors reached a maximum every thirty-three years, astronomers sought for an explanation of this remarkable fact. Professor

Adams, one of the discoverers of Neptune, showed that these minute Leonid meteors revolved round the Sun in a well-defined orbit in a period of thirty-three years, and that the orbit intersected that of our planet. It thus became apparent that meteors were distributed all round the orbit, but that there was a main swarm where the meteors were closely crowded together, and which, when crossing the Earth's orbit, was ploughed through by our planet

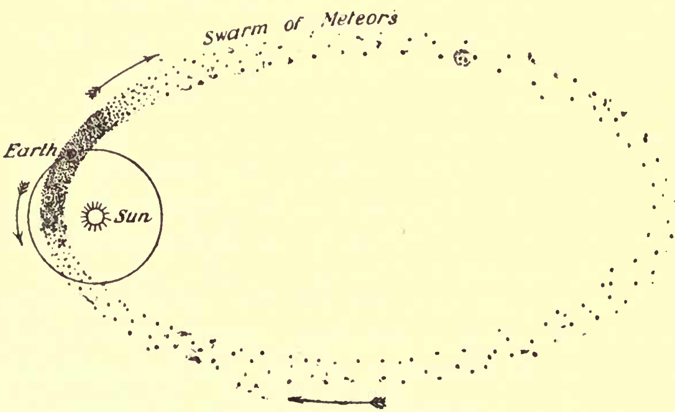


FIG. 6.—Passage of the Earth through the thickest portion of a Meteor Swarm. The Earth and the Meteors are here represented as approaching each other from opposite directions.

on its journey round the Sun. The failure of the main swarm to encounter the Earth in 1899 was a source of much difficulty to astronomers. However, the general opinion seems to be either that the swarm has become greatly worn out and extended along its orbit, or else that it was slightly deflected from its path by the action of some of the planets.

The most remarkable feature of the November meteors, however, was disclosed in 1866 by Professor Schiaparelli.

Having calculated the orbit of the meteors, he was impressed by its identity with the orbit of a comet, known as Tempel's Comet, which revolves round the Sun in thirty-three years and which was seen in 1866. Then, investigating the orbit of the August meteors, he found it to coincide with that of a bright comet which appeared in 1862. Finally, there came the discovery that the lost comet of Biela travelled in the same orbit as the Andromedids. Thus it was shown that the shooting stars so familiar to the Earth's inhabitants, and so long a mystery, were nothing less than the appendages of comets. Professor Schiaparelli says: "The meteoric currents are the products of the dissolution of comets, and consist of minute particles, which certain comets have abandoned along their orbits by reason of the disintegrating force which the Sun and planets exert on the rare materials of which they are composed."

There must be thousands of these meteoric currents in the solar system, and large numbers must cross the orbits of the other planets and encounter the various orbs. The result of this is that the Earth and the other planets are gradually increasing in size owing to the constant fall of meteoric matter. None of the ordinary shooting stars, of course, reach the ground whole. They are reduced to dust, which falls imperceptibly to the surface of the Earth.

There is another class of much larger meteoric bodies, and numbers of them fall to the ground without being reduced utterly to vapour. These are known variously as uranoliths, bolides, and aerolites. From ancient times there were traditions of the fall of stones from the sky, but it was not until 1803 that men of science came to believe in such phenomena. In that year an

aerolite fell at Laigle, in the department of the Orne, in France. A great aerolite, moving from south-west to north-east, perceived at Alençon, Caen, and Falaise, suddenly exploded with a frightful noise, and a number of meteoric stones, of which the largest weighed 20 lbs., were thrown to the ground, and were picked up still smoking. On July 23, 1872, on a beautiful summer's day, an aerolite fell in France, after a tremendous explosion which was heard for fifty miles round. It weighed no less than 126 lbs., and, by the force of its fall, dug a hole over five feet in depth. In April 1873, another great bolide fell near Rome. It had a velocity of thirty-seven miles a second on arrival in the Earth's atmosphere, and it was shattered to fragments. At Rowton, in Shropshire, on April 20, 1876, a piece of iron fell and buried itself in a field. When dug out, it was still hot. This, which is known as "the Rowton siderite," is now preserved in the British Museum. In 1881, a stone weighing three pounds fell in Yorkshire on the railway line, and made a hole eleven inches deep. On November 23, 1877, a meteorite exploded with a loud report over the town of Chester. A famous meteorite, which did not fall to the ground as a solid mass, was seen in December 21, 1876, in Kansas. It is thus described by Professor Howe, an American astronomer: "A superb fireball appeared over the State of Kansas, and moved thence eastward south of Chicago, across Indiana over Lake Erie, to Lake Ontario, where it disappeared. When nearly two hundred miles from Bloomington, Indiana, the meteor burst, and the inhabitants of that city saw a magnificent array of fireballs sweeping through the evening sky. After the excitement aroused by the marvellous spectacle was over, there came a tremendous crack like the reverberations of thunder.

The concussion which accompanied it led some to think that a light earthquake had shaken the town. How terrific must a detonation have been, which was so startling two hundred miles away, after the sound waves had been on their journey a quarter of an hour."

There has been much controversy among the astronomers as to the exact nature of these aerolites and fireballs. Laplace suggested about a hundred years ago that they might have been ejected from the volcanoes on the Moon; but this theory was soon abandoned, as was also a suggestion that they were ejected from the Sun. Sir Robert Ball and a number of other astronomers believe that these aerolites were ejected many ages ago by the volcanoes on the Earth's surface, then much more powerful and active than at present, and that they, having once been thrown out from our planet, would intersect the terrestrial orbit at each revolution. The alternative theory, supported by Professor Schiaparelli, Sir Norman Lockyer, and others, regards aerolites as simply larger members of meteor swarms, fragments of comets. This is confirmed by the fact that chemists have made analyses of the elements in these bodies raised to incandescence, and the presence has been detected of hydrocarbons, present also in comets. On the other hand, it is remarkable that, with one exception, an aerolite was never seen to fall to the ground during a meteoric shower. The exception took place on November 27, 1885, when during a shower of Andromedid meteors, a large bolide, weighing more than 8 lbs., fell at Mazapil in Mexico. Whether it was connected with the showers is not known.

The study of meteors has made great progress within

the last thirty years, thanks mainly to the work of a single observer, Mr. W. F. Denning of Bristol, the well-known English amateur astronomer. From 1872 to 1903, Mr. Denning determined the radiant points of 1172 meteor showers. In addition, he published in 1899 a catalogue of the radiant points of meteors numbering 4367. Thanks to Mr. Denning's work, the observation of meteors is a recognised branch of astronomy, and may be studied by any one who is interested in the subject and can make good observations.

A word may be said here of a phenomenon closely allied to the subject of meteors—the Zodiacal Light. This is a phenomenon which is much better seen in tropical than in temperate regions, but it is occasionally observed in Europe. A pearly glow is observed in the spring to spread over a portion of the sky just where the Sun has disappeared. In autumn the same thing is also to be seen before sunrise. It is in tropical regions, however, that it is seen in its full glory. Instead of being seen like a cone, as in temperate regions, it appears as a band of light. The portions nearest to the Sun are equal to the Milky Way in brilliance, while the more distant parts are much fainter, and are only visible owing to the clearness and purity of the atmosphere in the tropics.

The exact nature of the Zodiacal Light has long been more or less a mystery, but it seems to be generally believed among astronomers that the light is due to diffused dust, probably meteoric matter forming an outer appendage to the Sun. Opposite in the heavens is a much fainter phenomenon, generally known by its German name of the "Gegenschein" or counter-glow, probably also of meteoric composition.

THE SHOOTING STARS

Our survey of the solar system commenced with the infinitely great, the mighty orb of the Sun itself, and it has fittingly closed with a description of the infinitely little, the minute particles of cosmical dust which move round the central orb in obedience to the law of gravitation.

THE ZODIACAL LIGHT

A pearly radiance which is observed before sunset in spring and before sunrise in autumn. It is seen in all its glory in tropical regions. It is supposed to be due to meteoric matter beyond the Earth's orbit.

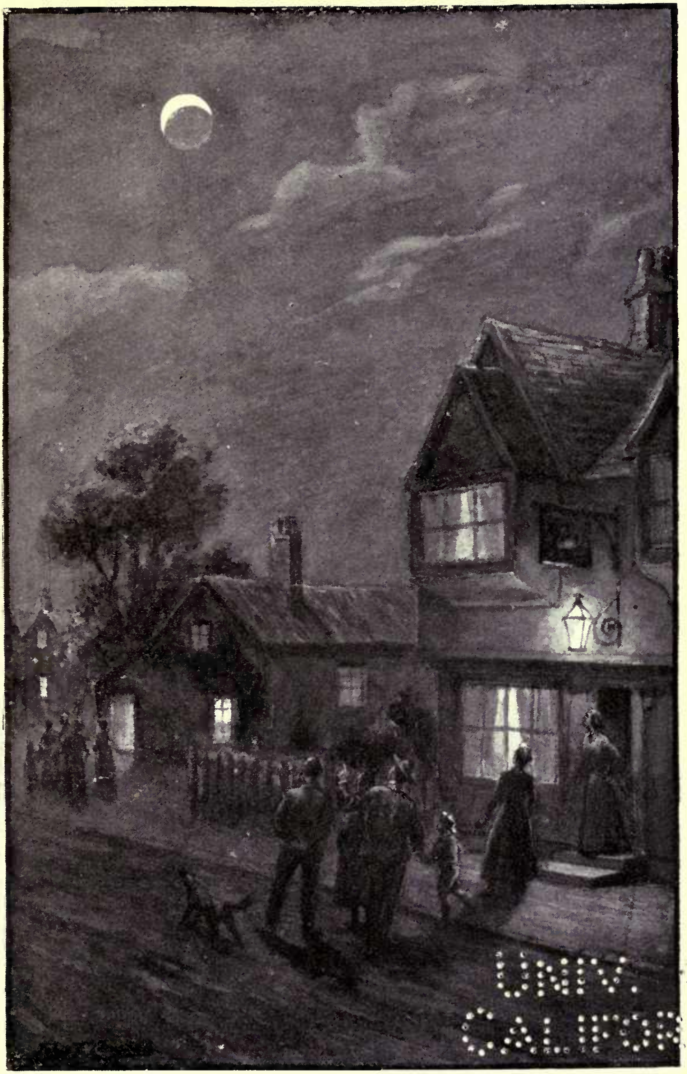
CHAPTER XVII

ECLIPSES AND TRANSITS

IN previous chapters a brief survey has been made of the solar system—the Sun and its family of planets and the comets and meteoric swarms. But before passing to a consideration of the vast universe outside of the solar system, it is well to consider the phenomena which arise from the movements of the various planets and the inclination of their orbits round the Sun. These facts give rise to the two classes of kindred phenomena known as eclipses and transits. We cannot properly understand the cause of the periodic occurrences known as eclipses until we fully realise the fact that every body shining by reflected light casts a shadow into space in a direction opposite to the source of illumination. Thus the Earth casts a shadow, and the Moon casts a shadow. Similarly Mars, Jupiter, Saturn, Venus, and the other planets cast shadows. But it is the shadows of the Earth and the Moon which cause the phenomena known to the Earth's inhabitants as eclipses of the Moon and eclipses of the Sun. The Earth casts a shadow into space; and when the Moon, the Earth, and the Sun are in a line with the Earth in the centre, the shadow of the Earth, which extends to and beyond the orbit of the Moon, is thrown in the direction of our satellite. If the Moon's orbit were exactly in the same plane or level as that of the Earth, our satellite would pass at every revolution through the shadow. In other

words, the Moon would be totally eclipsed and would become altogether invisible every time it reached the full phase. As a matter of fact, however, the Moon's orbit is not exactly in the same plane as that of the Earth, and it is only occasionally that an eclipse does take place. Sometimes an eclipse of the Moon is total—that is to say, the Moon is completely immersed in the Earth's shadow—and sometimes only partial, a portion of the Moon's disc remaining outside the true shadow. A total eclipse of the Moon is a very striking and beautiful phenomenon. As the Moon becomes more and more immersed in shadow, the illuminated portion becomes smaller and smaller until it completely disappears. The Moon is not, however, usually totally invisible. It generally assumes a dark copper-coloured hue, caused by the refraction of sunlight through the atmosphere of the Earth. This is believed to be due to the fact that the blue rays of the Sun are absorbed in passing through the atmosphere of the Earth, just as the sunset and sunrise skies are seen to assume a ruddy colour.

The Moon, however, does not always assume this tint during eclipses; sometimes there is a phenomenon known as the "black eclipse," when the Moon's surface is seen with a greyish-blue tint. Indeed, sometimes the Moon disappears altogether during eclipse. These variations are explained by a well-known astronomer in the following remarks: "It has been suggested that if the portion of the Earth's atmosphere through which the Sun's rays have to pass is tolerably free from aqueous vapour, the red rays will be absorbed, but not the blue rays; and the resulting illumination will either only render the Moon's surface visible with a greyish-blue tinge, or not visible at all. This will yield the 'black eclipse.'"



ECLIPSE OF THE MOON

Few celestial spectacles visible to observers in Britain are more striking than eclipses of the moon. The above represents the shadow creeping gradually over the bright disc of our satellite.

ECLIPSES AND TRANSITS

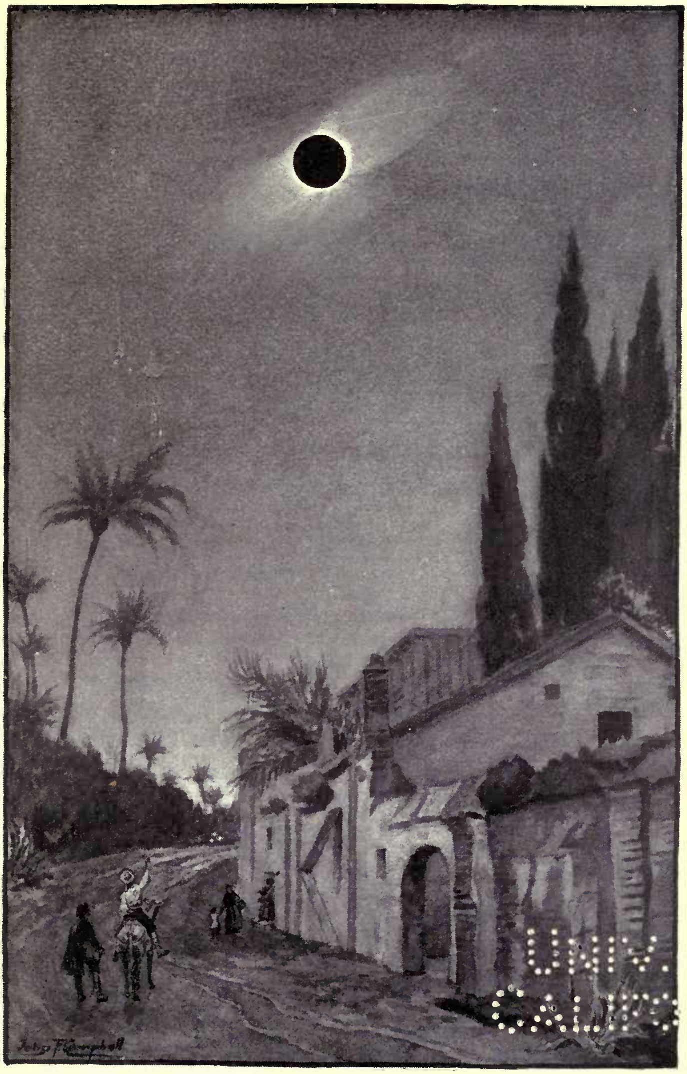
Eclipses of the Moon have long been a source of terror to the unlearned, and especially to savage tribes. Many instances might be given of the fear which the darkening of the Moon's light struck into the hearts of the ignorant. But one instance will suffice. An eclipse of the Moon took place when Columbus was in the island of Jamaica in 1504. The eclipse was total, and occurred very soon after sunset, and the event occurred at a most convenient time so far as the great explorer was concerned. In the "Life of Columbus," by Sir A. Helps, the narrative is told as follows :—

"The Indians refused to minister to their wants any longer; and famine was imminent. But just at this last extremity, the admiral, ever fertile in devices, bethought him of an expedient for re-establishing his influence over the Indians. His astronomical knowledge told him that on a certain night an eclipse of the Moon would take place. One would think that people living in the open air must be accustomed to see such eclipses sufficiently often not to be particularly astonished at them. But Columbus judged—and as the event proved, judged rightly—that by predicting the eclipse he would gain a reputation as a prophet, and command the respect and the obedience due to a person invested with supernatural powers. He assembled caciques of the neighbouring tribes. Then by means of an interpreter, he reproached them with refusing to continue to supply provisions to the Spaniards. 'The God who protects me,' he said, 'will punish you. You know what has happened to those of my followers who have rebelled against me, and the dangers which they encountered in their attempt to cross Haiti, while those who went at my command made the passage without difficulty. Soon, too, shall the divine vengeance fall on you; this very night shall the Moon change her colour and lose her light, in testimony of the evils which shall be sent upon you from the skies.'

"The night was fine: the Moon shone down in full brilliancy. But at the appointed time the predicted phenomenon took place, and the wild howls of the savages proclaimed their abject terror. They came in a body to Columbus and implored his intercession. They promised to let him want

for nothing if only he would avert this judgment. As an earnest of their sincerity, they collected hastily a quantity of food and offered it at his feet. At first, diplomatically hesitating, Columbus presently affected to be softened by their entreaties. He consented to intercede for them; and retiring to his cabin, performed, as they supposed, some mystic rite which should deliver them from the threatened punishment. Soon the terrible shadow passed away from the face of the Moon, and the gratitude of the savages was as deep as their previous terror; and henceforth there was no failure in the regular supply of provisions to the castaways."

It is well to bear in mind the differences between the two kinds of eclipses. While a lunar eclipse may last for several hours, a solar eclipse is a matter of a few minutes; and while a lunar eclipse can only take place at full Moon, a solar eclipse occurs at new Moon. Professor Gregory gives an instance of a novelist who, in one of his books, describes an eclipse of the sun which took place at *full* Moon and lasted half-an-hour! A little knowledge of the theory of eclipses would prevent such an error. As has been pointed out, an eclipse of the Moon is caused by the immersion of our satellite in the shadow of the Earth. A solar eclipse, on the other hand, is caused by the Moon's shadow falling on our planet. The Moon is a much smaller body than the Earth, and consequently it has a much smaller shadow. The shadow is too small to completely cover the Earth. It merely falls on a portion of the globe and at the parts immersed in the shadow the Sun is totally eclipsed. Solar eclipses last only a few minutes; and they are confined to a narrow strip known as the shadow track. At any given place on the Earth's surface, total eclipses of the Sun are rare. There has not been a total eclipse of the Sun visible in the United Kingdom since 1724, and there will not be



Eclipse of the Sun

The total solar eclipse of 1900, visible in Spain and Portugal. The black disc of the moon hides the glowing fire of the orb of day, and so allows us to see the brilliant prominences and the mystic, silvery corona.

another till 1927. However, though rare at given points on the surface of our planet, they are fairly frequent when the Earth is considered as a whole. There are three kinds of solar eclipses—total, partial, and annular. A total eclipse takes place when the Moon is at its nearest point to the Earth, and consequently appears just large enough to hide the Sun, and when our satellite is exactly in a line with the Earth and Sun. A partial eclipse occurs when the Moon is not exactly in a line with the Earth and Sun, and only covers a portion of the disc; while an annular eclipse takes place when the Moon is at its farthest point from the Earth, and does not appear to be large enough to cover the disc of the Sun, and thus we see an "annulus" or ring of light round the Moon's disc. Of these three classes, only total eclipses are useful to astronomers, and that only because of a peculiar combination of circumstances. Seen from the Earth, the Sun and Moon appear to be about the same size. Consequently, at a total eclipse the Moon is large enough to cover the large and glowing disc of the Sun, but not large enough, fortunately for the science of astronomy, to obscure the immediate surroundings of the orb of day.

When a solar eclipse takes place, expeditions are sent to observe the phenomena from all parts of the globe. Those who are unacquainted with the problems of solar astronomy may think it strange that so many expeditions are despatched to observe the obscuration of the Sun by the Moon, an event in itself of no particular importance. But owing to a combination of circumstances these obscurations have proved to be full of interest to the astronomer. The interposition of the Moon enables us to study the fainter and outlying portions of the Sun. In the words of Professor Campbell, the director of the Lick

Observatory: "Our Sun is one of the ordinary stars. In size perhaps it is only an average star, or it may be below the average. It is the only star near enough to us to show a disc. All other stars are as mathematical points, even when our greatest telescopes magnify them three thousand fold. The point image of a distant star includes all its details, and it must be studied as a whole, whereas the Sun can be studied in geometrical detail. It is not too much to say that our physical knowledge of the stars would be practically a blank if we had been unable to approach it through the study of our Sun. If we would

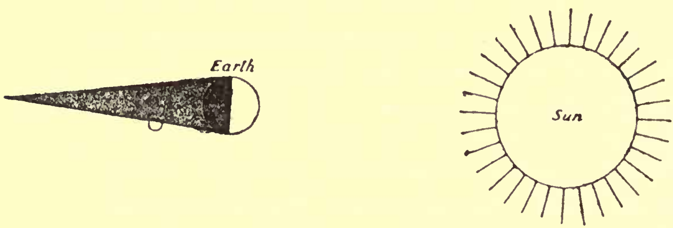


FIG. 7.—Total and Partial Eclipses of the Moon. The Moon is here shown in two positions: i.e. *entirely* plunged in the Earth's shadow and therefore totally eclipsed, and only *partly* plunged in it or partially eclipsed.

understand the other stars, we must first make a complete study of our own star. Several of the most interesting portions of our Sun are invisible except at times of solar eclipse. Our knowledge of the Sun will be incomplete until these portions are thoroughly understood; and this is the reason why eclipse expeditions are despatched, at great expense of time and money, to occupy stations within the narrow shadow belts."

The chief objects of study during total eclipses are the solar prominences and the reversing layer—or shallow solar

atmosphere—and the corona. The red prominences were formerly observable only during total eclipse, but in 1868 M. Janssen, viewing the total eclipse in India, and Sir Norman Lockyer, reasoning the matter out in England, discovered the method by which prominences could be observed in full sunlight, by means of the spectroscope. Accordingly, less attention is devoted to them during total eclipses. It may, however, be remarked that a class of objects known as "white" prominences, discovered by the late Professer Tacchini during the eclipse of 1883, are observable only on the occasion of a total eclipse. The corona is perhaps the chief object of interest in eclipse observations. The corona is a halo of light which makes its appearance as soon as the Sun is totally eclipsed, and remains in view only during the few minutes of totality. It is not a solar atmosphere, using that word in its proper sense, and it is probably of a compound nature. The spectroscope has had little chance to teach us much regarding the corona, owing to the faintness of the spectrum, and the short time of visibility. Professor Young considers that the coronal spectrum is composed of four superposed spectra—indicating, of course, that the corona is a compound phenomenon. First, there is the continuous spectrum due probably to incandescent dust, or solid and liquid particles near the Sun; secondly, the gaseous spectrum, indicating the presence of gases of a permanent nature. This spectrum is distinguished by a green line, which has not been identified with any terrestrial element. Thirdly, there is the continuous spectrum of reflected sunlight with the dark Fraunhofer lines, due to sunlight reflected from meteoric dust; and fourthly, the light reflected in the Earth's atmosphere. Drawings and photographs of the corona show that its size and shape vary in a

period of eleven years, corresponding with the changes of the solar spots, and even more nearly so with the period of the prominences. In fact, the late Professor Tacchini showed that the distribution of the prominences and the shape of the corona vary in harmony. There is still much uncertainty as to the actual nature of the corona, and as to what part electricity and magnetism may play in the phenomenon. In Professor Campbell's words: "Much has been written concerning a possible eruptive origin or about magnetic influences in shaping the forms of its streamers. . . . It is a surprising fact that, with all the changes of form, we do not know whether the materials

FIG. 8.—Total Eclipse of the Sun. From the position *A* the Sun cannot be seen, and it is entirely blotted out by the Moon. From *B* it is seen partially blotted out, because the Moon is to a certain degree in the way. From *C* no eclipse is seen, because the Moon does not come in the way.

composing the streamers are moving in or out, or both or neither. . . . Photographs of the corona should be secured for this purpose at widely separated stations—preferably at three or more stations—with essentially identical instruments and with equivalent exposures, in order that results may be as nearly comparable as possible."

The reversing layer of the Sun was discovered by Professor Young by means of the spectroscope, during the total eclipse of 1870, visible in Spain. As the solar crescent grew thinner, says Professor Young, "the dark lines of the spectrum itself gradually faded away, until all

at once, as suddenly as a bursting rocket shoots out its stars, the whole field of view was filled with bright lines more numerous than one could count. The phenomenon was so sudden, so unexpected, and so wonderfully beautiful as to force an involuntary exclamation." Professor Young concluded that every line in the spectrum had become bright, and hence the newly-disclosed layer of the Sun was called the "reversing layer." In 1896 its spectrum was photographed by an English observer.

The eclipse problem which appeals most to the popular mind is perhaps that of the possible existence of intra-Mercurial planets, already discussed in an earlier chapter. With the exception of some doubtful observations in 1878, eclipse observations have tended to negative the idea of even a small planet within the orbit of Mercury. Photographs were secured by Mr. W. H. Pickering in 1900, and by Professor Perrine in 1901, and on these no trace of an intra-Mercurial planet was seen. Professor Campbell made an exhaustive search during the total eclipse of August 30, 1905, visible in Spain, and no trace of an intra-Mercurial planet could be found.

For those who have never seen a total eclipse, the following description by an American writer, Mrs. Todd, is worth reading as illustrating the magnificence of the spectacle: "With frightful velocity the actual shadow of the Moon is often seen approaching, a tangible darkness advancing almost like a wall, swift as imagination, silent as doom. The immensity of Nature never comes quite so near as then, and strong must be the nerve not to quiver as this blue-black shadow rushes upon the spectator with incredible speed. . . . Sometimes the shadow engulfs the observers smoothly, sometimes apparently with jerks; but all the world might well be dead and cold and turned

to ashes. Often the very air seems to hold its breath for sympathy; at other times a lull suddenly awakens into a strange wind, blowing with unnatural effect. Then out upon the darkness, gruesome but sublime, flashes the glory of the incomparable corona, a silvery, soft, unearthly light, with radiant streamers, stretching at times millions of uncomprehended miles into space, while the rosy flaming protuberances skirt the black rim of the Moon in ethereal splendour. It becomes curiously cold, dew frequently falls, and the chill is frequently mental as well as physical. Suddenly, instantaneous as a lightning flash, an arrow of actual sunlight strikes the landscape, and Earth comes to life again, while corona and protuberance melt into the returning brilliance."

For many years eclipses both of the Sun and the Moon were a source of terror to mankind before proper knowledge had been gained of their true cause. And even to-day in uncivilised nations eclipses cause much consternation. In China, drums are beat and trumpets blown to frighten the "dragon" which is supposed to be devouring the Sun. The Hindus think that an eclipse causes food to be unclean, and consequently that it is unfit for use. The following cutting from an American newspaper in 1878 indicates the excitement caused among the Red Indians by the total solar eclipse of 29th July 1878: "Some of them threw themselves upon their knees, others flung themselves flat on the ground, face downwards; others cried and yelled in frantic excitement and terror. At last an old Indian stepped from the door of his lodge, pistol in hand, and, fixing his eyes on the darkened sun, mumbled a few unintelligible words, and, raising his arm, took direct aim at the luminary, fired off his pistol, and after throwing his arms about his head, retreated to his

own quarters. As it happened, that very instant was the conclusion of totality. The Indians beheld the glorious orb of day once more peep forth, and it was unanimously voted that the timely discharge of the pistol was the only thing that drove away the shadow, and saved them from the public inconvenience that would certainly have resulted from the entire extinction of the Sun."

Closely allied to eclipses are transits. Only two planets can be seen in transit across the Sun—Mercury and Venus. These transits occur like eclipses of the Sun, when the Sun, the Earth, and Mercury, or the Sun, the Earth, and Venus, are in a straight line. But owing to the very small apparent size of Mercury and Venus, as seen from the Earth, there is no eclipse. We merely see the black discs of the planets as spots on the glowing face of the Sun. The first observed transit of Venus was predicted by Kepler for 1631. These transits take place in pairs, separated by intervals of eight years, and the pairs are separated by intervals of 105½ and 121½ years. Kepler, although he had predicted the transit of 1631, was unaware of the fact that transits occur in pairs, and he did not expect another until 1761. A transit, however, took place in 1639, and was only witnessed by two persons. The story of its observation is an interesting one, and has long been a favourite among lovers of astronomy.

A young Englishman, Jeremiah Horrocks, a curate in the English Church, became at a very early age proficient in mathematical astronomy, and ascertained the fact that a transit of Venus, which Kepler had overlooked, would take place in 1639. The day he predicted for the transit happened to be a Sunday, and Horrocks could not observe continuously owing to his duties as a clergyman. At nine o'clock he was obliged to suspend observations, but at ten

he was again watching. He saw nothing on the Sun's disc. At noon he was again at church, but by one o'clock he was enabled to resume observations. To his sorrow, the sky clouded, and he almost abandoned hope of seeing the event he had predicted. But in the afternoon the clouds dispersed; the orb of day shone out once more, and the young astronomer beheld, to his intense delight, Venus in transit across the Sun. He had informed only one man, his young friend William Crabtree, of the occurrence of the event, and Crabtree also succeeded in observing the transit; but these two young men were the only observers of this occurrence, unexpected by the astronomers of the day. Horrocks, who gave promise of becoming one of the greatest astronomers of his time, did not long survive his triumph. He died shortly after at the early age of twenty-two.

The next pair of transits occurred in 1761 and 1769. Before they took place, however, Halley had pointed out that observations on Venus while in transit would lead to a correct measurement of the distance of the Sun, and consequently several expeditions were sent to observe these transits at different ends of the Earth. As an erroneous estimate of the Sun's distance was deduced from these measurements, astronomers looked eagerly forward to the next two transits in 1874 and 1882. As before, expeditions were despatched to all regions of the globe, but the results were disappointing, and astronomers have since devised better and more accurate methods of measuring the Sun's distance. The next pair of transits of Venus will take place in 2004 and 2012, and there will be another pair in 2117 and 2125. The reason of the rarity of these occurrences is the fact that the orbit of Venus is not exactly in the same plane as that of our Earth.

Transits of Mercury are not of so much interest as those

of Venus, and they are much more frequent. The last took place in 1907, and there will be another in 1917.

Closely allied both to eclipses and transits are occultations. The difference, however, between transits and occultations is that, while a transit is the passage of an apparently small body over an apparently large body, an occultation is the obscuration of a body apparently small by a body apparently large. Thus when the Moon passes over Jupiter or Mars, or a star, it is said to occult these objects.

In the system of Jupiter, which we only observe from a considerable distance, we can observe eclipses, transits, and occultations. We see the satellites immersed in the shadow, and we can also observe them in transit across the disc of their primary. In addition, we can observe Jupiter passing over and occulting these small bodies. Thus observation of the system of Jupiter gives us a practical illustration of the fact that eclipses, transits, and occultations are all kindred phenomena, arising from the fact that every body shining by reflected light casts a shadow into space.

CHAPTER XVIII

THE SUNS OF SPACE

WHEN we lift our eyes to the heavens on any clear moonless night, apparently innumerable luminous points of all degrees of brightness attract our attention. They are fixed in position relatively to one another, and they rise and set like the Sun. These are the stars—the stars proper, as distinguished from the planets or "wandering stars." These stars are the same orbs which shone down on Job, and Homer, and the ancient writers of thousands of years ago; and it is a solemn thought when we look upward to the star-spangled heavens that the same constellations and star groups met the gaze of generations upon generations which have long since passed away. Homer and Hesiod both refer to the constellations. Job mentions Orion and the Pleiades, and also, it is believed, the Great Bear. This fact proves that long ago, before astronomy was founded on a scientific basis, the early star-gazers had already divided the sky into constellations, and had given to them names. These star-groups are recognised by astronomers to-day, and one of the first steps for the beginner in astronomy is to learn the constellations. Just as in botany and geology respectively, it is necessary to know the various flowers and the different classes of rocks by name, so in astronomy it is essential to know the constellations, and to be able to follow them throughout the changing seasons.

THE SUNS OF SPACE

Most people are familiar with the Great Bear or Ursa Major, or at least with its most prominent part, the Plough. The Plough is not the most conspicuous constellation, but it is visible all the year round, and its shape is very easily remembered. But its position varies from month to month. It is essential to remember that the aspect of the heavens changes with the seasons. Not only do the stars appear to go round the Earth once in twenty-four hours, but, owing to the apparent motion of the Sun, the stars appear to rise and set four minutes earlier every night. The result is a constant change, gradual but steady, in the position of the stars at any given time, and at the end of the year the revolution is completed and the stars return to the places which they occupied a year before. One star in the heavens, however, scarcely changes its position at all. This is a fairly bright object in the northern sky, known as the Pole Star, so called because the axis of the Earth points almost exactly to it. That is to say, were we standing exactly at the North Pole, we should see the Pole Star almost exactly overhead. The Pole Star therefore remains practically fixed in position, while all the stars in the sky appear to revolve round it. The farther the star from the Pole, the wider the circle which it appears to describe. Thus, the stars of Ursa Minor, the constellation in which the Pole Star is situated, describe smaller circles than the stars in the Plough. But even the stars in the Plough describe a relatively small circle. They are never below the horizon, and their ceaseless revolution round the Pole is an index of the changing seasons. For instance, in the spring evenings, the Plough is almost directly overhead; in summer evenings it is in the north-west; in autumn evenings it is low down in the north, in winter evenings in the north-east.

On the opposite side of the Pole from the Plough is the constellation Cassiopeia. It is shaped like the letter W. Between Cassiopeia and the Plough is Auriga, a star group dominated by a brilliant star known as Capella, and on the other side of the Pole from Auriga is Lyra, another star group also dominated by a bright star known as Vega. These four constellations are almost always visible, though sometimes Auriga and Lyra are lost in the haze of the horizon. In England these two stars disappear for a certain time in the haze of the horizon; but in Scotland and northern latitudes they are nearly always to be seen.

These four constellations, moving around the Pole, constitute what has been well named "the great star clock of the north." As Mr. E. W. Maunder has said: "To watch these northern constellations, as they follow each other in ceaseless procession round the Pole, is one of the most impressive spectacles to a mind capable of realising the significance of what is seen. We are spectators of the movement of one of Nature's machines, the vastness of the scale of which, and the absolutely perfect smoothness and regularity of whose working, so utterly dwarf the mightiest work accomplished by man."

Once a knowledge of the northern heavens has been gained, it is a comparatively easy matter to learn the names and outlines of the remaining constellations. Each season has its own particular groups. For instance, Orion, Taurus, and Canis Major are the great constellations of winter, even though they may be seen in spring and autumn; but it is in winter that they are seen to most advantage, and that they are visible at the most convenient hours of the night. Similarly with the other stars. In spring we have Leo, Virgo, and Boötes dominating our skies; in summer we have Lyra, Scorpio, Hercules, Corona Borealis; in

autumn Cygnus, Aquila, Aries, Perseus, and other groups. As the seasons advance, the reappearance of a familiar constellation lends a new charm and interest to the evening walk. Not only the constellations themselves, but the stars which compose them have their own designation. Some of the brighter stars, such as Sirius, Vega, Arcturus, and Capella have proper names, but the vast majority are designated by letters of the Greek alphabet. Thus the bright star Aldebaran is also known as Alpha Tauri, *Tauri* being the genitive of the Latin noun Taurus. Similarly, Sirius is Alpha Canis Majoris. When the Greek letters in each constellation are exhausted, numbers are used also with the genitive of the Latin noun. Thus we talk of 61 Cygni, 42 Comæ Berenices, &c.

So much for the stars as they appear; but the science of astronomy enables us to understand what the stars really are. To us they appear little twinkling points of light suspended above the clouds, useful on a moonless night. Astronomy teaches us that, so far from being merely little points of light, the stars are suns. This great truth gradually dawned on mankind. Even Copernicus had very hazy notions as to the nature of the stars. But as astronomy developed, and as better instruments were invented, our information concerning the distant orbs increased, until to-day our knowledge of the stars is considerable. It was the great Sir William Herschel who first studied the stars systematically; and so many and important were his discoveries, and so great was the interest in the stars aroused by his investigations, that since the commencement of his work stellar astronomy—as distinguished from planetary astronomy—has gone from triumph to triumph. The stars are suns. This is the first great truth which we must bear in mind. Very

insignificant they seem, even the brighter objects among them being almost obliterated by the moonlight, utterly extinguished by the sunlight, and seeming very small and unimportant beside Jupiter, Venus, and Mars. As we saw in preceding chapters, distance is often very deceptive. The Moon, for instance, shines many times more brightly than Jupiter, and yet it belongs to an altogether inferior order of bodies. It is only a satellite, the attendant of our world, while Jupiter is a planet many times larger than the Earth. Jupiter shines many times more brilliantly than Sirius, the brightest of the stars. Yet Jupiter is to the stars as the Moon is to Jupiter; for the stars are suns, and Jupiter sinks to utter insignificance compared with even the faintest of the stars. It belongs to an altogether inferior order of bodies.

It is the vast distance of the stars which explains their apparent insignificance—a distance so vast that for many years it was hopeless to attempt to measure it. In a previous chapter explanation was made of the principle of measurement of the celestial distances and of the meaning of the term "parallax." If the measurement of the distances of the Sun and planets is difficult, it will easily be understood how much more difficult is the measurement of the distances of the far-away stars. The fact that the stars showed no measurable displacement greatly perplexed Copernicus. It was argued—and rightly—by the opponents of the Copernican system, that if the Earth had an annual revolution round the Sun, there ought to be a corresponding displacement of the stars owing to the observer's change of position. But the most careful measurements of the astronomers of that day failed to show any displacement. Copernicus had therefore to claim for the stars a much greater distance than he was

willing to; for in those days men had a very inadequate idea of the Universe. Tycho Brahe, the last of the great pre-telescopic astronomers, also attacked the question and attempted to find this displacement, but he failed. After the invention of the telescope many attempts were made, but in vain. The greatest astronomers were baffled, among them such men as Bradley and Herschel; and it was not until the third decade of the nineteenth century that the first milestone of Infinity, so to speak, was reached.

Three attempts were made independently to measure this displacement. In 1835 the German astronomer Struve commenced a series of measurements on the bright star Vega, but the distance which he deduced from his measurements proved so far from the truth that the result was practically useless. Other two attempts proved more successful. The German astronomer Bessel succeeded in measuring the distance of a faint little star of the fifth magnitude numbered 61 in the constellation Cygnus. At the same time Thomas Henderson, the great Scottish astronomer, afterwards Astronomer Royal of Scotland, measured the distance of what has proved to be the nearest star. While employed as the Astronomer Royal at the Cape of Good Hope, he made a series of observations on the brilliant star known as Alpha Centauri, one of the brightest stars in the heavens, and he succeeded in measuring its distance. This distance is about twenty-five billions of miles. Such figures are unthinkable. The entire solar system is about five thousand millions of miles in diameter—a great diameter, it is true, but inconsiderable when compared to the enormous distance of the nearest star. Our solar system is indeed a little island in space, a mere speck in the greater system of the stars. It is difficult to obtain a true idea of this vast

distance. The late Dr. Dolmage, in his book "Astronomy of To-Day," gives an unique illustration which should help the reader a little, as it were, in comprehending the incomprehensibleness of this distance :—"What is a million? It is a thousand thousands. But what is a billion? It is a million millions. Consider for a moment. A million of millions. That means a million, each unit of which is itself a million. Here is a way of trying to realise this gigantic number. A million seconds make only eleven and a half days and nights. But a billion will make actually more than thirty thousand years."

An idea of the immense distance of the nearest star may be gained from consideration of the fact that if the distance from the Sun to Neptune were represented by ten feet, Alpha Centauri would be fourteen miles away. But the true method by which we can properly comprehend the distances of the stars is by considering the velocity of light. Light crosses the diameter of the entire solar system in eight hours; yet it takes about four years to span the gulf which separates our system from the nearest star. What, then, of the more distant stars? 61 Cygni is about fifty-three billions of miles away, and light requires about seven years to reach us from that orb. Sirius, the most brilliant star in the sky, is distant fifty-eight billions of miles, and light is eight years on the journey.

In the vast majority of cases there is no visible displacement of the stars in the sky, and their distances cannot be measured. An idea of the great difficulty of measuring this parallax or displacement may be gathered from the remark of an American writer, Mr. G. P. Serviss, that the displacement "is about equal to the apparent distance between the heads of two pins placed an inch apart and

viewed from a distance of 180 miles." The wonder is not that astronomers have measured the distance of so few stars, but that they have succeeded in measuring the distances of any. Comparatively few distances have been measured with any approach to accuracy. A number have been measured roughly and a number estimated. It might be supposed that the brightest stars, those of the first magnitude, are nearest to the Earth; but such is not the case. Sirius, it is true, is among the nearer stars, but it is at a greater distance than 61 Cygni, an insignificant little star of the fifth magnitude. Thus we see that, just as there are great diversities among the planets, so the stars are far from being all of the same size. A tolerably accurate measurement of the distance of the brilliant star Arcturus has been made. So vast is the distance, that light takes over two hundred years to travel to our system from its glowing surface. How enormous therefore must be the star which shines so brilliantly from so vast a distance. The diameter of Arcturus is believed to be about sixty-two millions of miles. Compared with Arcturus, our Sun, great and splendid orb as he seems to us, is a puny dwarf. Mr. Garret P. Serviss says of this enormous sun: "Imagine the Earth and other planets constituting the solar system removed to Arcturus and set revolving round it in orbits of the same forms and sizes as those in which they circle about the Sun. Poor Mercury! For that little planet it would indeed be a jump from the frying-pan into the fire, because as it rushed to perihelion, the point of its orbit nearest the Sun, Mercury would plunge more than 2,500,000 miles beneath the surface of the giant star. Venus and the Earth would melt like snow-flakes at the mouth of a furnace. Even far-away Neptune would swelter in torrid heat." Another enormous sun is

Rigel, one of the two brilliant orbs in Orion. So distant is this body that Sir David Gill utterly failed to measure its distance. Capella, in Auriga, is yet another gigantic orb. According to Mr. Gore, it is about fourteen millions of miles in diameter, and is equal in volume to four thousand suns such as ours. A little reflection on these enormous sizes shows us that everything in the Universe is relative. To us on Earth a range of mountains is gigantic; the Earth itself is so vast that we cannot conceive of it as a globe at all, and we can only regard a portion of it at a time. And what of the Sun? To us its size is overwhelming. We cannot realise a diameter a hundred times that of our Earth. And as to the stars, we may repeat the figures which denote their diameters, but we cannot grasp what these figures mean. The stars themselves are of all sizes and at all distances. All are enormously distant, but some are much nearer than others. All are enormously large, but some much larger than others. Of the two thousand visible at a time to the unaided eye, we have measured the distances of very few, and have calculated the sizes of the merest handful. And yet at the very beginning of our investigations among the suns of space, we learn that indeed, "One star differeth from another star in glory."

CHAPTER XIX

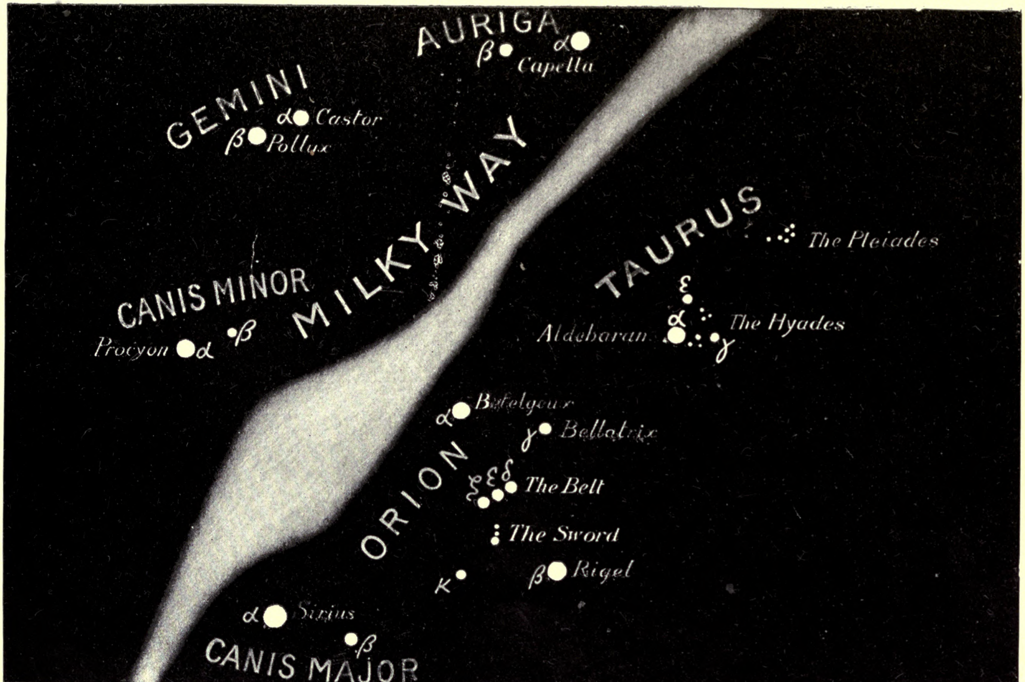
THE REVELATIONS OF STARLIGHT

WHEN we cast an upward glance to the heavens and look at the stars, we little realise what may be called the revelations of starlight; we little imagine that in the rays of the stars are borne to us most of the secrets of the Universe, and that the light rays from Immensity tell us a story which for wonder, mystery, and majesty is unrivalled in the realms of the imagination.

In the chapter on the Sun, reference was made to the spectroscopic method of observing that luminary, and to the knowledge which has been gained from a study of the band of coloured light known as the solar spectrum. It is much more difficult to observe the spectra of the various stars than the spectrum of the Sun, owing to the relative feebleness of starlight. However, since 1863 astronomers have made rapid progress in this branch of knowledge. In that year the late Sir William Huggins commenced his work in this department, by a particular study of two stars of the first magnitude, Betelgeux and Aldebaran. In the former star he ascertained the existence of the elements sodium, iron, calcium, magnesium, and bismuth, and in the latter the same elements, with the addition of tellurium, antimony, and mercury. Thus, for the first time, the rays of starlight had revealed to humanity the constitution of the suns of space.

Secchi, a well-known Italian astronomer, made a classifi-

cation of the stars in the heavens about the same time that Sir William Huggins started his observations. It was known many years before that just as the Sun had a different spectrum from any of the stars, so the stars differed among themselves. It was shown, however, by Secchi that the stars could be divided into four well-defined groups—white stars, yellow stars, red stars, and dark-red stars, according to the variations in their spectra. Although other more scientific classifications have since been proposed and adopted, the first classification gives us a general idea of the different types of stars. When we turn our eyes to the heavens, we see that the stars are not all of the same colour. We at once note the bluish white of Sirius, the red colour of Betelgeux, the orange-red hue of Aldebaran. When we consider the bright stars according to their spectra, we find that Sirius, Vega, Rigel, Altair, Regulus are included in the class known as the white stars or the Sirian stars, from their brightest example. In the second type are included Capella, Arcturus, Aldebaran, Procyon, Pollux, and the Pole Star. The spectrum of our Sun, in fact, is of this type, and hence this class of orbs is known as the group of solar or yellow stars. The stars of the third type are much less numerous. Betelgeux and Antares are the most notable representatives of this type. The fourth type includes stars of a deeper red, none of which are bright enough to command the attention of the casual observer. The first type has been sub-divided by the late Dr. Vogel into two sub-classes, the Orion type and the Sirian type. The stars of the Orion type are so called because most of the stars in the constellation Orion are of that class. They are distinguished by the presence in their atmospheres of the element helium. Rigel, in Orion, is one of the



Some Brilliant Constellations

The brightest star in the sky is Sirius; it is so far off that the light from it takes eight and a half years to reach the Earth. The galaxy known as the "Milky Way" is shown reaching from side to side of the plate. It is composed of a host of very faint stars, too faint to be separately distinguished with the naked eye.

typical stars of this group, and a massive and gigantic orb it appears to be. Its mass is no less than 34,000 times that of the Sun, the enormous orb whose size overwhelms the minds of mortals. Rigel, however, as the late Miss Clerke pointed out, "is not massive in the proportion of its luminosity." It gives about eight thousand times more light than our Sun, "but the Sun is dimmed to about one-third of its native lustre by effects of absorption which are virtually absent from the star. Hence a total light emission 8000 times greater would represent a radiating surface only 2667 times more expansive than the solar photosphere. Stars of the helium variety are composed of highly rarefied materials."

Sirius and Vega may be taken as typical stars of the second sub-division of stars of the first type. Stars of the solar type are of various sizes. Alpha Centauri, one of our nearer neighbours in space, seems to be a sun in many respects similar to our own. Another star of the solar type which deserves mention is Arcturus, or Alpha, of the constellation Boötes. Its spectrum is of the solar type, but so far as size is concerned, as mentioned in the last chapter, it dwarfs the Sun to utter insignificance, and apparently belongs to a higher order of suns than the ruler of our own planetary system.

In a work like the present it is obviously impossible to present the technical details of the researches of astronomers on the spectra of the stars. One interesting discovery may be mentioned. It might be supposed that stars of the different types are scattered over the sky at random, but such is not the case. The white stars congregate on the whole in a definite region of the heavens, that marked by the Milky Way or Galaxy; while the solar stars are on the whole distributed with some approach to uni-

formity. The meaning of this difference in distribution of the two types will be unfolded in a later chapter.

Although most of our knowledge of starlight is due to the marvellous revelations of the spectroscope, a considerable amount of knowledge has been gained from a study of starlight by the telescope, and indeed by the unaided eye. Perhaps the most remarkable objects in the heavens are the new or temporary stars—orbs which blaze out in the sky where no previous stars have been seen, and which then sink into invisibility. Many instances of temporary stars have been recorded. A temporary star is believed to have appeared in the year 134 B.C., and to have suggested to Hipparchus, the famous Greek astronomer, the idea of forming a catalogue of stars. The first temporary star, however, of which we have any authentic record was observed by Tycho Brahe, and is always known as Tycho's Star. The famous Danish astronomer was not, however, the discoverer of the star. It was detected by a German at Wittenberg on August 6, 1572, whereas Tycho did not notice it until November 11. Looking up to the sky one evening, Tycho was astounded to see the appearance of the well-known constellation Cassiopeia entirely changed by the appearance of a new and brilliant star, far outshining the other stars of the group. When first seen by Tycho Brahe, the new star was brighter than Jupiter, and when it reached its greatest visibility it was fully equal to Venus. So bright, indeed, was the new star that in a clear sky it was visible in full daylight. In March 1574 it ceased to be visible to the unaided eye.

Another bright star, usually associated with the name of Kepler, appeared in 1604. On 10th October of that year, one of Kepler's pupils noticed that a new and brilliant star had made its appearance in the constellation

Ophinchus. The planets Mars, Jupiter, and Saturn were close together in the same constellation, and it was easy to make comparisons between the new star and the planets. It was estimated as brighter than Mars and Jupiter, and indeed as equal to Venus. The star, which was also studied by Galileo, disappeared in March 1606, having been visible for about seventeen months.

These two stars were the brightest temporary stars recorded in history. The next authentic instance of a similar object was the appearance of a much less imposing stellar phenomenon. By the middle of the nineteenth century the discovery of temporary stars was a much easier matter than at the time of Galileo, owing to the increased power of telescopes as well as the increased number of astronomers. The star detected by the English observer Hind, on April 28, 1848, never exceeded the fifth magnitude in brilliancy. More striking was the star of 1866, popularly known as "blaze star." John Birmingham, an amateur astronomer at Tuam, in Ireland, observing the heavens with the unaided eye on the evening of May 12, 1866, detected a brilliant star in the constellation Corona Borealis. It was then of the second magnitude, and equal in brilliance to the brightest star of the constellation. It must have increased very rapidly, for Schmidt, of Athens, one of the most competent observers of the day, affirmed that when he scanned the same part of the sky four hours earlier it was not then visible, although he was sure that no strange star brighter than the fifth magnitude could have escaped his notice. This star was notable from the fact that for the first time the newly invented spectroscope was applied to the study of temporary stars. The star was particularly studied by Sir William Huggins, who discerned four

brilliant lines in the spectrum. The principal line represented hydrogen. It was thus obvious that the cause of the outburst was the eruption of vast masses of hydrogen gas. The new star declined very rapidly in brilliance, although not so rapidly as it increased. Nine days after its appearance, it was invisible to the unaided eye. The remarkable thing about this star was that it was not actually a temporary star in the true sense of the word, as it had been observed ten years earlier as an ordinary telescopic star, invisible to the unaided eye. The appearance of this star caused much interest among astronomers. The marvellous feature of the outburst was that in a few hours the star increased its brilliance by about nine hundred times. Mr. Peck, Astronomer to the City of Edinburgh, has the following remarks in this connection: "What would likely be the result if a conflagration like that which took place on this remote sun were at any time to happen to our Sun? Not only would all the various forms of life on Earth be utterly destroyed, but on all the members of our solar system there would be such a change effected that if any life existed even on the remote Neptune it would at once be completely extinguished. Probably the life that existed on the whole system of worlds that circled round this distant star must have been annihilated, and as the heat and light of this star increased so very suddenly, there could have been given but short warning to the inhabitants of these worlds."

Another new star made its appearance ten years later. On November 24, 1876, Schmidt noticed a strange star of the third magnitude in Cygnus. It was closely similar to the new star of 1866, hydrogen being present in abundance. A new star which appeared in Andromeda, in 1885, is

interesting from the fact that an attempt was made to measure its distance from the solar system. So vast, however, was this distance, that the attempt was a failure.

The next temporary star was detected in January 1892, in the constellation Auriga, by Dr. Anderson, of Edinburgh, a famous observer of variable stars. At the time of discovery it was of the fifth magnitude. Remarkably enough, this new star had been visible to the unaided eye for some time before Dr. Anderson's discovery, but had never been noticed. It had imprinted its image on photographs taken in America by Professor Pickering. These photographs showed that on November 20 it was a little over the fourth magnitude. It then began to decline, and when discovered visually it was of the fifth magnitude. Then, after its discovery it brightened up again, and on February 14 was between the fourth and fifth magnitudes. After this it steadily declined until April, when it was of the fifteenth magnitude, but in August astronomers were astounded to find that it had again increased, this time to the ninth. Since then it has steadily diminished.

A number of insignificant temporary stars made their appearance between 1892 and 1901, being mostly detected by photography; these are of little interest except to the professional astronomer, and may be passed over here. But on February 21, 1901, a magnificent temporary star —the most brilliant since Kepler's in 1604—shone out in the constellation Perseus. It was so brilliant as to be detected by a number of independent observers, including Dr. Anderson, the discoverer of the previous new star, and Mr. J. E. Gore. When first seen by Dr. Anderson it was of the second magnitude, and a photograph taken on the previous evening showed that it must have been

then below the twelfth magnitude, as it was invisible on the photograph. On the evening of February 23 the star was equal to Capella, and of the first magnitude. But it did not long retain its pre-eminence. By March 1 it was of the second magnitude, and by March 6 of the third. In September it faded to the sixth magnitude, while in March 1902 it was of the eighth magnitude, and in July of the twelfth.

Since that date two other new stars have been discovered, both faint, in 1903 and 1905 respectively. Many theories have been advanced to account for temporary stars. The most probable of these various theories is that put forward by Professor Seeliger, who regards these outbursts as due to the passage of dark extinct stars through masses of nebulous matter. The dark stars are raised to incandescence through friction, just as the meteors are ignited by passing through the Earth's atmosphere. Temporary stars differ in many respects from variable stars. But one body in the heavens, which seems to belong partly to both classes, deserves mention. This star is known as Eta Argus, and is invisible in Europe. At present it is of the seventh magnitude, and cannot be seen without the aid of a telescope. In the seventeenth century it was of the fourth magnitude, and a hundred years later of the second, while in 1837 it was equal to the first magnitude star Alpha Centauri. Then it began to decrease. In 1843, however, it again blazed up, and became the second star in the heavens, surpassed only by Sirius. Since then it has steadily declined, and is still inconspicuous.

There are many known variable stars in the heavens, the catalogues containing thousands of them. The first variable was first seen in 1596 by Fabricius, a Dutch

observer. It is known as Mira Ceti or the Wonderful Star of Cetus. It has been thus under observation for over three centuries. Its period is about 331 days, but it is not very regular, and sometimes at its maximum it is much more brilliant than at other times. For instance, in 1906 it was brighter than the second magnitude. Its variations appear to result from great internal disturbances. There are many stars which appear to vary in much the same manner designated as variable stars of long periods.

Other two classes of variables are known as "Algol stars," and short-period variables. The Algol variables are so called from the brightest star of their type, Algol, or Beta Persei. The fluctuations in the light of Algol, which occupy 2 days 20 hours 48 minutes 51 seconds, are believed to have been discovered by the ancient Arabian astronomers, and were re-discovered by Goodricke, an English astronomer in 1782. Goodricke suggested that the variations in the light of Algol were caused by the partial eclipse of the star's light by the interposition of a dark satellite star just as the Sun's light is cut off by the Moon. In modern times the late Professor Vogel of Potsdam confirmed this theory in a remarkable—indeed marvellous—way by means of the spectroscope. The explanation of this method is rather abstruse, and it is somewhat difficult to comprehend without a knowledge of physics.

One of the most remarkable uses of the spectroscope is due to the fact that by its means motions may be measured. In 1842 Doppler, a German physicist, expressed the view that the colour of a luminous body would be changed by its motion of approach or recession, and that a larger number of light waves would be entering the eye of the observer if the body were approaching than if it were retreating. The late Miss Clerke thus illustrates Doppler's

principle: "Suppose shots to be fired at a target at fixed intervals of time. If the marksman advances say twenty paces between each discharge of his rifle, it is evident that the shots will fall faster on the target than if he stood still; if, on the contrary, he retires by the same amount, they will strike at correspondingly longer intervals." In an approaching body the lines in the spectrum will be displaced towards one end of it; on a receding body towards the other. By this method several astronomers succeeded in measuring the motions of the stars, and it was obvious to Vogel that, as Algol and its satellite are revolving round a common centre of gravity, Algol would before each eclipse be retreating from our system, and after each eclipse approaching. Vogel found that such was the case, thus proving the theory conclusively.

Not only did he confirm the theory, but he has arrived at the conclusion that Algol is a star 1,000,000 miles in diameter, the dark companion being 800,000 miles—about the size of the Sun. The distance between the two is about 3,000,000 miles. From irregularities in the movements of Algol, an American astronomer is of opinion that Algol and its dark companion revolve round another dark globe in 180 years, at a distance of about 1,800,000,000 miles. Thus, though we have never seen the satellite of Algol, we know that it exists; and though we cannot tell its distance from us, we can tell its probable size. The variable stars of short periods, such as the famous Beta Lyræ, are also explained by the mutual revolution of one or more bodies, and many a thorny question concerning variable stars has been solved by this method. Thus, the study of variable stars indicates the existence of systems of stars—stars in revolution round their centre of gravity. This brings us to the subject of the next chapter—systems of stars.

CHAPTER XX

SYSTEMS OF STARS

IN the well-known constellation of the Plough there is a bright star known as Mizar or Zeta Ursæ Majoris. Close by is an orb much fainter, which is only seen to advantage in a binocular or small telescope. These two stars, Mizar and Alcor, form the finest examples in the heavens to the unaided eye of what is known as a double star. Other examples are to be found in Beta Cygni, a magnificent pair of coloured suns, which is revealed in a small telescope, and in Alpha Capricorni, which a field glass will show as double. A considerable number of double stars are known. The first to be discovered telescopically was found in 1664, when an English astronomer, while observing a comet in the constellation Aries, incidentally noticed that the star Gamma of that constellation consisted of two stars close together.

For many years it was believed that these double stars were not really double, and that their apparent connection was merely the result of perspective. It was supposed that the one star might be millions or billions of miles in space behind the other, and that the two appeared connected only because they happened to lie in the same line of vision. This view was generally held until, in 1802, it was shown by Sir William Herschel that many double stars were real stellar systems. In that year he announced that in the case of many of these doubles the two stars

were in mutual revolution—in other words, that the law of gravitation extended to the stars. Thus he showed that the law of gravitation which Newton found applicable to the solar system was not merely a local law, but existed throughout the length and breadth of the Universe.

To distinguish between mere "optical doubles," of which there are a considerable number in the heavens, and revolving stars he gave the latter the name of "binary" stars, and this name is retained by them to the present day. Many of the brightest stars in the heavens are binaries. Among them must be mentioned Alpha Centauri, our nearest neighbour in space; Castor, one of the two well-known "Twins" in the constellation Gemini; Sirius, the brightest star in the sky, and Procyon, another first-magnitude orb. The detection of the satellites of these two stars reminds us of the discovery of Neptune. In 1844, Bessel, the great German astronomer, discovered that Sirius was being attracted off its path by the action of some unseen body. Orbits were calculated by astronomers, and one calculator assigned a period of revolution of about fifty years to the satellite star. In 1861 the star was discovered close to the indicated spot, and its period of revolution turned out to be about fifty years. In the case of Procyon, the existence of a satellite star was also predicted before it was seen, and the actual period of revolution agrees with that which was deduced by the calculators—a fact which illustrates the remarkable accuracy of astronomical calculation.

The number of double stars in the heavens is to be counted by thousands, and the orbits of many of these have been calculated successfully. The greatest names in this department of astronomy have been the Herschels, father and son; the Struves, father and son; and Professor

S. W. Burnham of Chicago, the greatest living observer of double stars, who has himself discovered over twelve hundred of these objects.

Thanks to the spectroscopic method of determining motion in the line of vision, mentioned in connection with Algol, many double stars have been discovered, the components of which are too close together ever to be separately seen. Mizar in Ursa Major, which with Alcor forms a wide double and a connected system, was found by Professor E. C. Pickering, by means of the spectroscopic method, to be itself double; and Spica, the brightest star of Virgo, was found to be also double. In the case of the last-named star the companion is almost completely dark. Since these discoveries were made in 1889 and 1890, "the astronomy of the invisible," as this line of research is called, has come to be regarded as a recognised branch of astronomy, and many of these close double stars are now known.

Double stars—that is, telescopic doubles—often exhibit great varieties of colour. Perhaps the most beautiful example within the range of small telescopes is Beta Cygni. A view of this beautiful star is a never-to-be-forgotten spectacle. The larger star is reddish yellow, and the smaller one blue. Antares, a fiery red star in Scorpio, of the first magnitude, is attended by a small green companion star, and there are many other instances. For long it was thought that star colours were merely the effect of contrast. This, however, was disproved by the spectroscopic observations of Sir William Huggins. The colours of the stars are real. A vivid description of the scene observed by a dweller on any one of the planets revolving round these stars is given by the late Mr. Proctor in "The Expanse of Heaven." He supposes one of the suns to be blue and the other orange, the planet

being placed in the same position as the Earth is in our system. There would be an endless variety of sights in the heavens. The blue sun and orange sun might rise together, and produce "double day"; or the blue sun might rise as the orange sun was setting, and there would be no night. In Proctor's own words: "The skies must be exceedingly beautiful. Our clouds have their silver lining because it is the light of the Sun which illumines them. Our summer sky presents glowing white clouds to our view, and at other times we see the various shades between whiteness and an almost black hue. . . . But imagine how beautiful the scene must be when those parts of a cloud which would otherwise appear simply darker shine with a fuller blue light or with a fuller orange light. How gorgeous again must be the colouring of the clouds which fleck the sky when one or other sun is setting. . . . There are infinite varieties of arrangement depending on the relative dimensions of the suns of a double-star system, and in their colours there are immense varieties—yellow and purple suns, red and green suns, suns of golden yellow, cream-white, rose-colour, and so on; companion suns of lilac, russet, citron, fawn, buff, and olive hue in endless numbers. . . . I conceive that few thoughts can be more striking and instructive than are those suggested by this infinite wealth of beauty and variety." It must be clearly borne in mind that these systems are completely different from ours. In the solar system, we have one bright star and a number of planets revolving round it. There may or may not be planets in these systems; but if such worlds do exist, they will, as Proctor points out, certainly experience very varied sights in their skies. Double stars of all classes are so numerous in the heavens, that it may well be that these systems,

long considered an exception, may be as prevalent as the systems of one star, and a number of secondary worlds. Flammarion in his "Popular Astronomy" has the following reflection on double stars, which is worthy of reproduction, so high are the thoughts which it suggests to the mind: "The double stars are so many *stellar dials* suspended in the heavens, marking without stop, in their majestic silence, the inexorable march of time, which glides away on high as here, and showing to the Earth from the depth of their unfathomable distance the years and centuries of other universes, the eternity of the veritable Empyrean! Eternal clocks of space! your motion does not stop; your finger, like that of destiny, shows to beings and things the everlasting wheel which rises to the summits of life and plunges into the abysses of death. And from our lower abode we may read in your perpetual motion the decree of our terrestrial fate, which bears along our poor history and sweeps away our generation like a whirlwind of dust lying on the roads of the sky, while you continue to revolve in silence in the mysterious depths of Infinitude!"

Double stars are not the only type of stellar systems. There are triple, quadruple, and multiple stars. One famous system is Zeta Cancri. This system has been particularly studied by Professor Seeliger of Munich, who has shown that in all probability three bright stars in this system revolve round a dark body, apparently the most massive of the four. From multiple stars to groups and clusters of suns is but a step, and in such groups as the Hyades and Pleiades we have the next step in the scale of stellar systems. The group of the Pleiades is the most famous star group, or indeed cluster, in the heavens. It has been known from the earliest ages, and is referred to

in the Book of Job and by Greek authors. The Pleiades, which in the winter months is one of the most noticeable objects in the sky, consists of six or seven stars visible to the unaided eye. Of these stars the largest is known as Alcyone. With a telescope a great number of stars are to be seen in the Pleiades, and photography has disclosed the fact that many of the principal stars in the cluster are enveloped in nebulous matter. The Hyades, surrounding the bright star Aldebaran, forms a more scattered group of stars. Another interesting group, or rather cluster, is "Præsepe" or "the Bee Hive" in the constellation Cancer.

The grandest clusters in the heavens are only to be seen with the aid of telescopes. Perhaps the two finest in the whole sky are those in Hercules and Centaurus. The cluster in Hercules may be seen with the aid of a small telescope, but it is only to be seen with advantage when a large instrument is applied to it. The Scottish astronomer, Nichol of Glasgow, remarked that "probably no one who has beheld this cluster for the first time in a telescope of great power can refrain from a shout of wonder."

Let us consider the conditions on a planet situated in the middle of such a cluster as that in Hercules. Such a world would know no night. Day would be everlasting. If such a world turned on its axis, sun after sun, blazing with light and heat, would pass across its sky in solemn procession. Indeed the perpetual state of affairs on such a planet is equal to the spectacle which we on Earth should behold if all the stars seen on the darkest and clearest night were to increase in brightness until even the faintest of them shone with a sufficient radiance to banish night. Herschel considered that this cluster contained fourteen thousand stars.

Omega Centauri, only to be seen in the southern hemi-

sphere, is a closely compressed cluster of thousands of stars. It may be seen with the unaided eye as a hazy star, but a good telescope is required to show it in all its beauty and grandeur. In the southern hemisphere are also situated two remarkable objects, the Magellanic Clouds, individually known as the Nubecula Major and the Nubecula Minor. Both of these are roughly of a circular form. Mr. Gore says of these two clusters: "The larger cloud covers over forty-two square degrees, and when examined with a telescope is found to consist of upward of 600 stars of the sixth to the tenth magnitude, with numerous fainter ones, and nearly 300 clusters and nebulæ. The smaller Magellanic Cloud, Nubecula Minor, is fainter to the eye and not so rich in the telescope." These clusters are in many ways the most remarkable objects in the heavens—mighty collections of suns, and probably worlds, at an enormous distance from our world. Here we observe what Tennyson with scientific accuracy describes as

> "Clusters and beds of worlds and bee-like swarms
> Of suns and starry streams."

CHAPTER XXI

THE MOTIONS OF THE STARS

THE stars are generally designated as "fixed" stars to distinguish them from the planets or "wandering" stars. On a first consideration of the subject, the name "fixed stars" seems to describe very accurately the chief characteristics of these groups. While the planets move about through the Zodiacal constellations, the stars preserve relatively to one another the same positions. The constellation Orion preserves throughout the ages its well-known form. Similarly the Plough shines down on us to-day as it did on the kingdom of Israel and on the plains of Troy. So that for all practical purposes we are correct in speaking of the fixed stars. And yet, scientifically speaking, we are wrong. The stars are no more fixed than are the planets. Indeed, many of the stars are moving through space with a velocity far greater than the swiftest of the planets. But so distant are the stars, so deep are they sunk in the depths of space, that in the course of hundreds, even thousands of years, the casual star-gazer can detect no difference in their positions.

But casual star-gazing, or even intelligent observation of the stars with the unaided eye, is a very different thing from careful and patient measurement. The ancient astronomers, even when they measured carefully the positions of the stars, detected no change in their positions,

and hence they believed the stars to be literally fixed to the inside of a huge sphere, which rotated once in twenty-four hours. And even after it had been shown that the Earth rotated on its axis, and that there was no literal sphere, the idea was still maintained that the stars were motionless.

At length it was found in 1715 that the star Arcturus was in motion. Halley compared its position as noted by his own observations with its position in the old catalogues, and he found that unmistakably the star had moved. Here was an extraordinary discovery. The fixed stars were not fixed. Since the time of Halley the proper motions, as they are called, of many other stars have been measured and estimated, until at the present moment, in the estimate of Professor Dyson, Astronomer Royal of Scotland, the proper motions of ten thousand stars have been measured. The stars whose motions have been measured travel with various velocities. The swiftest star of all is an eighth magnitude star in the southern hemisphere. This little object is not designated by a name, or a letter, or even an ordinary number. Its designation is "Gould's Cordova Zones, V Hour, 243." This is the swiftest known star in the heavens, and an idea of its vast distance may be obtained from the statement that the star would require two hundred years to move over a space equal to the Moon's apparent diameter. The next swiftest star is an insignificant star in Ursa Major which is known as "1830 Groombridge," that being its number in the catalogue of the astronomer Groombridge, who lived early in the last century. This star would in 265 years move over a space in the heavens equal to the Sun's apparent diameter, and in 185,000 years would complete a revolution of the whole sky.

Next to "1830 Groombridge" come two small stars in the southern hemisphere, and next, our nearer neighbours in space, 61 Cygni and Alpha Centauri, the distances of both of which have been measured. The real velocity of Groombridge 1830 is 128 miles a second; 61 Cygni moves at the rate of 30 miles per second; while the bright star Arcturus has been calculated to have a velocity of no less than 376 miles per second.

The Sun is a star. It possesses points in common with many of the suns of space, and, as the stars are moving, is it not possible that the Sun is also moving? At first sight it looks almost impossible to determine the motion of our Sun, if it does move. For it is obvious that if the Sun is moving through space, the Earth and other planets will be carried along with it, just as the Moon is carried along with the Earth. It is quite plain, therefore, that if the Sun does move, there will be a corresponding displacement of the stars, just as there is in our solar system a displacement of the Sun resulting from the motion of the Earth. But here a complication enters into the problem. If the stars were stationary, it would be quite an easy matter to detect from their displacements the motion of the Sun; but they are not stationary. Each star is moving through space in its own particular direction, and with its own particular velocity. Thus the problem becomes almost insuperable. Nevertheless it was tackled and solved over a hundred years ago, and its solution is one of those brilliant strokes of genius which astronomy owes to Herschel. It was obvious to Herschel that if the Sun is moving in a certain direction the stars in front will appear to open out and those behind to close up. Of course, as already mentioned, this is complicated by the motions of the stars themselves.

From a photograph taken in 1906 by Dr. Max Wolf, of Heidelberg

THE GREAT NEBULA IN ORION

This nebula is generally admitted to be one of the finest sights in the heavens.

Nevertheless Herschel, by an ingenious method of separating the real from the apparent motions of seven stars, was able to show that the Sun was moving towards a point in the constellation Hercules near to the apparent position of the star Lambda Herculis. Herschel believed the rate of the solar motion to be "certainly not less than the Earth has in her annual orbit." However, the general opinion of astronomers is that the velocity of the Sun is about eleven miles per second, somewhat less than the rate of our planet's motion in its orbit. It has now been ascertained that the point towards which the Sun is moving is not in Hercules, but in the neighbouring constellation Lyra, near to the star known as Delta Lyræ.

If we give this great discovery a moment's consideration, we cannot but be impressed with it. Not only does the Earth revolve round the Sun, but it follows the Sun in its endless journey through space. And not only is the Earth moving round the Sun at the rate of eighteen miles a second, but it is being carried along with it at the rate of eleven miles a second. Yet so vast is the space surrounding the solar system, and so completely isolated from the rest of the Universe, that although the Sun has been moving at the rapid rate of eleven miles per second throughout the time in which the human race has been in existence, yet the resulting displacements of the stars are utterly imperceptible to the unaided eye. Sir Robert Ball explains very clearly the enormity of the stellar distances and the isolation of the solar system in the following words: "The Sun, and with it the whole solar system, is bound on a voyage to that part of the sky which is marked by the star Delta Lyræ. It also appears that the speed with which the motion is urged is such as to bring us every day about 700,000 miles nearer to this

part of the sky. As you look at Delta Lyræ to-night, you may reflect that within the last twenty-four hours you have travelled toward it through a distance of nearly three-quarters of a million of miles. So great are the stellar distances that a period of not less than 180,000 years would be required before our system, even moving at this impetuous speed, could traverse a distance equal to that by which we are separated from the nearest of the stars."

Mention has been made of the marvellous method of finding by means of the spectroscope the motions of bodies in the line of vision. In this way the motions of many stars have been measured. When we measure the "proper motion" of a star over the face of the sky, we are in reality only measuring that part of the motion which is across the line of vision. The star may be moving towards or away from the Earth, but that part of the motion could never be detected by the purely telescopic method. It is here that Doppler's method comes in conveniently. The first results were obtained by the late Sir William Huggins as long ago as 1868. Very satisfactory results were reached by the late Dr. Vogel, who applied photography to this branch of research. Vogel found that ten miles a second was the average velocity of stars in the direct line of sight. Some stars, however, proved swifter, and some slower than the average. Thus the brilliant star Aldebaran is moving away from the solar system at the rate of thirty miles a second.

Perhaps the most remarkable fact about the motions of the stars is that some stars share their proper motions with others. Flammarion mentions the case of Regulus, the brightest star in Leo, which travels at the same rate as a faint star of the eighth magnitude. When more than two stars have a common proper motion, the phenomenon

is known as "star drift." The best known instance is afforded by five of the seven stars of the Plough. Each of these stars moves with the same velocity in the same direction. Not only do these stars have the same velocity across the line of sight; the spectroscope proves that they have the same motion in the line of vision also, so that they certainly form a connected system, although they are separated from one another by billions of miles.

Does any law regulate the motions of the stars? This problem has exercised the minds of astronomers for many years, and has not been solved. But this is not to be wondered at. Even after the motions of the planets were known and could be predicted, the law of the planetary motions was unknown, and many years, indeed centuries, elapsed before it was shown that the planets were in revolution around the Sun. It is therefore not remarkable that no law has been detected. Several speculations have been made as to the revolution of the stars round some central body. A well-known German astronomer, Argelander, suggested that the central body of the stellar system was situated in the constellation Perseus. Mädler, another famous German astronomer, after an elaborate investigation, believed himself to have obtained satisfactory evidence that the Sun and all the other stars were in revolution round Alcyone, the chief star of the Pleiades; but neither of these theories has been accepted, and at the present time astronomers do not believe that there is a central sun, large and powerful enough to control the motions of the other stars. Flammarion, in one of his picturesque illustrations, compares our solar system to an absolute monarchy with the Sun as despot, and the system of the stars to a federated republic without a dominating authority.

CHAPTER XXII

THE FIRE MIST

PERHAPS the most remarkable objects in the heavens are the hazy celestial clouds known as nebulæ, or, as they have been picturesquely called, the fire mist. Even with the unaided eye, two of the most famous nebulæ in the heavens are partly visible. On a clear winter's night, the middle star of the "sword" of Orion is seen to be somewhat hazy, and even a small hand telescope will show it as a cloud on the dark background of the sky. This is the famous object known as the Great Nebula in Orion, considered by all astronomers to be one of the finest sights in the heavens. Similarly a keen eye will detect a hazy spot of light in the constellation Andromeda, which the smallest optical power resolves into a nebula. These are the two most famous nebulæ in the heavens. The Andromeda nebula is the more easily seen without telescopic aid, yet the other is considered by far the grander object of the two. Even in a small telescope the Orion nebula is certainly the more interesting and awe inspiring. It was first observed by a Swiss named Cysat in 1618, and it is somewhat remarkable that it was not discovered by Galileo. The first observation on it was made by Huyghens, who described the Great Nebula as follows: "In the sword of Orion are three stars quite close together. In 1656, as I chanced to be viewing the middle one of these with the telescope, instead of a single star, twelve showed themselves. Three of these almost

touched each other, and with four others shone through a nebula, so that the space around them seemed far brighter than the rest of the heavens, which was entirely clear and appeared quite black." Increase of telescopic power has shown the Orion nebula to be more and more complex, until to-day it is known to be part of a mighty nebulous system, enveloping the entire constellation of Orion.

Another of the diffused nebulæ not visible to the unaided eye, is that known as the "North America" Nebula in Cygnus. This nebula was discovered by Dr. Wolf, who was so impressed by its resemblance to the map of North America, that he gave it the name which it has retained ever since. The great nebula in Andromeda is a much less diffused mass than that in Orion. Its distance from the solar system seems to be very great. One of the ablest of modern astronomers has calculated its possible diameter, and he finds it to be so great that light would require many years to pass from one side of the nebula to the other. It has been calculated that if on a map of this object we were to lay down a map of the entire solar system drawn to scale, it would be a mere speck compared to the nebula.

What are the nebulæ? In the end of the eighteenth century the general idea was that the nebulæ were all star clusters too far away for the stars composing them to be visible separately. Herschel, after sharing this view for some time, came to the conclusion that the nebulous light was "not of a starry nature," but was composed of huge masses of glowing gas. There was nothing, however, to prove beyond doubt the correctness of his view, and even Sir David Brewster in 1854, in "More Worlds than One," declared that increase of telescopic power would resolve all the nebulæ, which in his view were all star clusters at enormous distances. Herschel's son, Sir John Herschel, also shared this view.

Telescope after telescope was turned on the nebulæ with the hope of resolving them into stars, but the attempts proved futile. The gigantic reflector erected by the Earl of Rosse at his estate in Ireland in 1845, was turned to the nebulæ in the hope that at last they would be resolved into stars. Lord Rosse himself considered that he had partially resolved the Orion nebulæ, and that a little increase of telescopic power would prove beyond all doubt that it was a star cluster. The refractor of Cambridge, Massachusetts, U.S.A., was said to have also accomplished the resolution of the nebulæ.

Only five years after Kirchoff's discovery of the principles of spectrum analysis, Sir William Huggins, on August 29, 1864, turned the spectroscope on the nebulæ in Draco. The spectrum showed that the nebulæ were a mass of incandescent gas. In Sir William Huggins' own words, "these nebulæ are shown by the prism to be enormous gaseous systems." He then observed the Orion nebula, and showed it to be also gaseous. After all, Herschel had been right, and other astronomers wrong. Huggins also proved that the Ring nebula in Lyra and the "Dumb Bell" nebula are gaseous. The spectra of the great nebula in Andromeda and the great spiral nebula are more complicated, and they are considered to be in a further stage of their existence than the great nebulæ in Orion.

There are many various shapes of nebulæ. Some, like the Andromeda nebula, are elliptical; others, like the Ring nebula in Lyra, annular; others round like planets, and known as "planetary nebula"; others widely diffused like the nebula in Orion and the nebula surrounding Eta Argus; others spiral, like the nebula in Canes Venatici, and many other varieties. Some years ago the late Professor Keeler, director of the Lick Observatory, devoted himself to nebular astronomy. The results which he gained were striking. On one occasion he was photographing

From a photograph taken in 1909 by Dr. Max Wolf

THE GREAT SPIRAL NEBULA

a certain nebula in the constellation Pegasus, and was amazed, on developing the plate, to find that not only that nebula but twenty others had been photographed. In the constellation Andromeda he actually found thirty-two nebulæ reproduced on a small photographic plate. This shows the immense number of nebulæ. He considered that with the Crossley reflector, the instrument with which he made his observations, 120,000 new nebulæ would be visible, half of these probably spiral. More recently Professor Perrine, of the same Observatory, announces that probably 300,000 nebulæ are within reach of the same instrument.

The gaseous nebulæ in the heavens are to be counted by thousands. We cannot measure the distance from us to any of them, and therefore we are unable even to estimate their size. Sir Robert Ball, writing on the great nebula in Orion, says: "As the eye follows the ramifications of the great nebula ever fading away in brightness until it dissolves in the background of the sky; as we look at the multitudes of stars which sparkle out from the depths of the great glowing gas; as we ponder on the marvellous outlines of a portion of the nebula, we are tempted to ask what the true magnitude of this object must really be. . . . The only means of learning the true length and breadth of a celestial object depends upon our having first discovered the distance from us at which the object is situated. Unhappily we are entirely ignorant of what this distance may be in the case of the great nebula in Orion. . . . We shall, however, certainly not err on the side of exaggeration if we assert that the great nebula must be many millions of times larger than that group of bodies which we call the Solar System."

We can form no idea of the appearance of the nebulæ at close quarters. We can say that the planets are globes like the Earth, with days, nights, seasons, and years; we can assert that the stars are suns, like our Sun, probably

with planets revolving round them; we can even form some idea of what the scene must be at the centre of a star cluster; but in the case of a nebula our imagination fails. Their immense size, their enormous distance from our system, and the mighty changes which are believed to be in progress in their midst, show us in a new light the insignificance of the Earth, and increase our astonishment when we remember that only three hundred years ago our little planet was believed to be the centre of the Universe.

Many telescopic observations have been made on nebulæ in the hope of determining whether, like the stars, they have a proper motion, but all these attempts have been futile. Professor Keeler, however, was successful in measuring the velocities of ten nebulæ in the line of sight by means of the spectroscopic method. He found a well-known nebula in Draco to be moving towards the solar system at the rate of forty miles a second, and the Orion nebula to be receding at the rate of eleven miles a second. Thus the mighty fire mists are sailing through space on an endless journey —just as the stars and the comets are. We cannot fully comprehend the meaning of our own thoughts when we reflect that an enormous diffused mass of gas, many times larger than the solar system, is in rapid motion through the depths of space, covering forty miles in one second of time. Truly the Universe is more wonderful than we can comprehend.

CHAPTER XXIII

THE GALAXY

WHEN we turn our eyes to the heavens on any clear moonless light, we cannot but be impressed with the majestic stream of milky light which spans the heavens like a mighty arch. This is the Milky Way, or Galaxy—the ground plan of the stars. The Galaxy traverses the constellations Scorpio, Sagittarius, Aquila, Cygnus, Cepheus, Cassiopeia, Perseus, Auriga, Gemini, Canis Major, Monoceros, Argo, Crua, Ara, and Centaurus. It has been known from the earliest ages, and many speculations as to its true nature were made by the ancient Greeks. In the opinion of Aristotle, the Galaxy was due to atmospheric vapours, while Anaxagoras held the absurd opinion that it was the shadow of the Earth. Several acute thinkers among the Greeks, however, were of the opinion that the Galaxy was nothing more than a collection of very faint stars, too faint to be separately seen. When Galileo turned his newly invented telescope to the heavens, this theory was at once found to be the true one. For centuries the Galaxy has arrested the attention not only of men of science, but of all thoughtful observers of the heavens, and it is referred to by many of the poets. Wordsworth calls it, "Heaven's broad causeway paved with stars," and Milton's beautiful description of it is not only poetical, but scientific :—

> "A broad and ample road whose dust is gold,
> And pavement stars, as stars to thee appear,

Seen in the Galaxy, that Milky Way,
Which nightly, as a circling zone thou seest,
Powdered with stars."

This "broad and ample road" was specially studied by Galileo; but, of course, his telescope was far too small to resolve the Galaxy into stars. "There were parts of the Galaxy," writes Mr. Peck, "that Galileo's telescope utterly failed to penetrate, and there still remained in the background that same misty light which had for so many centuries engaged the attention of astronomers. With every increase of telescopic power, more stars were seen and greater depths were reached, but only to find, as Galileo had found, that some parts would require a more powerful instrument to reveal the individual stars that by being crowded so closely together caused this cloudy light. And even when Sir William Herschel applied his powerful reflectors to this part of the heavens and reached still farther depths, there was yet seen that same milky light which speaks of the myriads of stars still to be revealed. Nay, even Lord Rosse, with his gigantic telescope, could not resolve some of the luminous patches scattered throughout the Milky Way."

Since the time of Lord Rosse, photography has been applied to the Galaxy with striking success by three distinguished photographers of the sky—Professor Max Wolf, Professor Barnard, and the late Dr. Isaac Roberts. These astronomers have shown the constitution of the Milky Way to be exceedingly complex. The stars are, in many cases, intermixed with nebulous matter. Another remarkable feature of the Galaxy is the presence in it of rifts and chasms. There is, for instance, a typical chasm in the southern Milky Way known as the "Coal-sack"; and there are many others. Dr. Wolf's remarkable series of photo-

From a photograph taken in 1905 by Dr. Max Wolf

REGION OF THE HEAVENS IN CANIS MAJOR

Each of the points of light on the photograph is a sun ; millions and billions of miles separate these points of light.

graphs, too, reveal many smaller rifts which were previously unknown. Through these rifts we evidently get a view into the depths of space beyond the Galaxy, into the region which has been designated the "darkness behind the stars."

Another remarkable feature of the Galaxy is the existence of streams of stars. In Cygnus, close to the star Deneb or Alpha Cygni, there is a typical instance of a star stream, which may be observed with a binocular. Many others of these are to be seen in the Galaxy—stars obviously connected, which may yet be separated by enormous distances.

Let us consider what streams of suns are. They are aggregations of vast orbs, some larger and some smaller than the mighty Sun; each of them possibly the centre of a system of planets, abodes probably of human life. It is difficult to conceive of the utter insignificance of our planet, indeed of our Sun and solar system, compared with these mighty star streams. Seen from these orbs the Sun itself, if visible at all, will be seen as a faint little star, and the Earth and planets of course will be totally invisible. If the Sun were to be suddenly extinguished, the consequences would be very serious so far as our world and the other planets were concerned; all life would disappear from the surface of the Earth, which would move through space as a dead world. But the extinction of the Sun, with the consequent destruction of the human race, would be absolutely unimportant, if not unknown, to the Universe at large. As Sir Robert Ball has expressed it: "All the stars of heaven would continue to shine as before. Not a point in one of the constellations would be altered, not a variation in the brightness, not a change in the hue of any star could be noticed. The thousands of nebulæ and clusters

would be absolutely unaltered; in fact, the total extinction of the Sun would be hardly remarked in the newspapers published in the Pleiades or in Orion. There might possibly be a little line somewhere in an odd corner to the effect 'Mr. So-and-So, our well-known astronomer, has noticed that a tiny star, inconspicuous to the eye, and absolutely of no importance whatever, has now become invisible.'"

The Galaxy is no mere isolated phenomenon in the heavens. It is the ground plan of the Universe. It was shown by Herschel, a hundred years ago, that there are more stars in the regions of the heavens near to the Milky Way than in the opposite regions; in other words the stars increase up to the Galaxy, which seems to be a region of stellar clustering. It has been shown by Professor Schiaparelli and the late Mr. Proctor, that the stars visible to the unaided eye are more numerous on and near the Galaxy, as well as the telescopic stars. What light does this throw on the great question of the construction of the Universe, of the relation of the entire number of stars which are to be seen with the most powerful telescope to one another, and to the Galaxy itself? The prevailing idea seems to be that the entire agglomeration of stars visible to the most powerful telescopes, known as the Stellar Universe, forms a globe of stars, and that the Galaxy forms the equatorial zone of that globe; that there is greater clustering—that is to say, that the stars are closer together—in the Galaxy than elsewhere in the Universe. At the same time there may be a greater extension of stars in the line of our vision in the direction of the Galaxy.

Although the above seems a fairly good outline of the entire Universe of Stars, there are a number of local pecu-

From a photograph taken in 1901 by Dr. Max Wolf

THE GREAT NEBULA IN ANDROMEDA

liarities among the stars. For instance, as already mentioned, stars of the first or white type are most prevalent on or near the Galaxy. The investigations of Professor Kāpteyn, a distinguished Dutch astronomer, have disclosed the fact that the near vicinity of our Sun contains almost exclusively stars of the solar or yellow type, the same class as our own Sun. Another remarkable fact is, that the stars in the constellation Orion have, with the exception of Betelgeux, similar spectra, and that these stars are closely intermixed with the great nebulæ. Professor Kāpteyn's studies have also told us of the possible existence of two great streams of stars moving in opposite directions. These facts are all very disconnected, but the reason of their disconnection is that astronomers have not yet learned enough of the Stellar Universe and of its dominant feature, the Galaxy, to form a complete theory of its constitution. As Mr. Gore has well remarked, "The Copernicus of the sidereal system has not yet arrived, and it may be many years or even centuries before this great problem is satisfactorily solved."

One point in connection with the system of the stars, however, is tolerably certain. The collection of orbs which we call the Universe of Stars is limited in extent. Probably space is infinite, but the number of stars in the stellar system is not infinite. There may be five hundred million or more, but they cannot be infinite in number. There is a well-known law of optics which shows that if the stars were infinite in number the whole sky would shine with the brightness of the Sun as a result of the blazing of an infinite number of suns, extending to an infinite distance. In some parts of the heavens, too, the limits of the Universe seem to have been reached. For instance, at a part of the sky diametrically opposite to the Milky Way,

Sir William Herschel with his mighty telescope saw a certain number of stars. An Italian observer, Professor Celoria, using quite a small instrument, saw exactly the same number of stars. This showed that Herschel's telescope was unable to show any more stars in that direction than the little instrument of Celoria, because the stars in that part of the Universe have a definite limit. At the same time its diameter is almost unthinkable, even on the most moderate estimate. The Universe extends undoubtedly to an enormous distance—a distance which we can only estimate and which we are unable to conceive. Yet it is limited in extent.

But what, after all, is the Stellar Universe? It is not *the* Universe. It is merely one of a number of similar systems scattered throughout space. We have never seen such systems. Nor can we expect to see them. When astronomers are still unable completely to pierce through our own stellar systems, it would be futile to expect to catch a glimpse of another system. Reasoning, however, from first principles, astronomers are on the whole inclined to believe in the existence of other systems, external universes. Mr. Gore has made a calculation of the possible distance of one of these external universes. Assuming that the distance of the nearest of these systems is proportionate to that separating our system from Alpha Centauri, he reaches the astounding conclusion that the distance of the nearest of these external universes is no less than 520,149,600,000,000,000,000 miles. This is, of course, pure speculation. The external universe, if it exists, as it probably does, may be at a greater distance, but it is most unlikely to be any nearer. Our minds are overwhelmed with the thoughts suggested by this calculation. We cannot fully comprehend the extent of the

system of the stars; still less can we conceive of an external system.

Mr. Gore, overwhelmed with the marvels disclosed in this calculation, with the revelation of Infinity which astronomy gives to us, closes his investigations with the following beautiful thought: "The numbers of stars and systems really existing, but invisible to us, may be practically infinite. Could we speed our flight through space on angel wings beyond the confines of our limited universe to a distance so great that the interval which separates us from the remotest fixed star might be considered as merely a step on our celestial journey, what further creations might not then be revealed to our wondering vision? Systems of a higher order might then be unfolded to our view, compared with which the whole of our visible heavens might appear like a grain of sand on the ocean shore—systems perhaps stretching to Infinity before us and reaching at last the glorious 'mansions' of the Almighty, the Throne of the Eternal."

CHAPTER XXIV

THE ORIGIN OF THE UNIVERSE

ONE of the most fascinating branches of astronomy is that in which astronomers have attempted to discover the method of the evolution and development of the Universe. Most of us believe that, "In the beginning God created the heavens and the earth," and that "the earth was without form and void." Both of these sublime truths are taught by science as well as by theology. Science cannot go beyond that; it can only with all reverence indicate the method by which the Creator has brought into existence this stupendous Universe.

The general opinion of astronomers is that the method of creation is disclosed to us in the remarkable law of evolution; indeed, the law of evolution as developed in the Nebular theory, may now be regarded as an established scientific truth. The first hint of the Nebular theory—the development of the solar system from masses of nebulous matter—was given by the Scottish astronomer, James Ferguson. It was in a private letter that Ferguson first put forward his views of the Nebular theory, an effort to explain the method of the Creation as described in Genesis. He was followed by the German philosopher Kant, who, in 1754, propounded his views on the development of the planetary system from a chaotic nebula or mass of incandescent gas. The complete Nebular theory

was, however, put forward independently about a hundred years ago by Herschel and the French astronomer Laplace. These two astronomers reached the Nebular theory by different methods—Laplace by mathematical reasoning, and Herschel by direct observation of the heavens with his great telescope.

Laplace noticed that in the solar system the planets all revolved round the Sun in the same direction, from west to east, and that each of the satellites known to him revolved round the planets in the same direction. There was no obvious reason why the planets should revolve in this direction more than in any other. Another fact noted by Laplace was that all the planets revolved round the Sun and the satellites round their primaries in almost the same plane or level as the Earth moved round the Sun. There was no obvious reason why the planets should all move in this plane, yet, as a well-known astronomer has remarked, "there are a million chances to one in favour of the supposition that the disposition of the movements of the planets has not been the result of chance." Laplace accordingly put forward his explanation. This was that the solar system had originally existed in the form of a mass of incandescent gas, or nebula. In contracting, he pointed out, this nebula had shed rings which condensed to form the planets, and, having condensed almost to its utmost, now forms the Sun, the central body of the solar system, which is still contracting. Laplace had never seen a nebula, for the simple reason that he did not possess a telescope; such an object probably existed in his imagination only. His great contemporary Herschel had seen hundreds of nebulæ, had classified them, studied them, theorised concerning them. Quite independently of Laplace, Herschel was led to the view that these nebulæ he was

observing would in course of time develop into systems of suns and planets, and that conversely the solar system must have once existed in the form of a great diffused nebula.

Since the days of these astronomers, a further addition to our knowledge has been made by Professor Darwin, of Cambridge. According to his researches, millions of years ago the Earth and Moon were not separate bodies. At that time our planet was a gaseous mass, spinning on its axis in a very short period, between three and five hours. In consequence of this rapid rotation, and in consequence of the tide raised by the Sun, the Earth split in two, and the smaller of these two parts now forms the Moon. This hypothesis, rigorously developed by mathematics, is distinctly supplementary to the Nebular theory, and explains in greater detail the particular development of that part of the solar domain known as the Earth-Moon system.[1]

Since the days of Herschel and Laplace, astronomical science has progressed remarkably. The Nebular theory has been modified with the advance of knowledge; but the central idea, the development of the Universe, as we know it, from masses of incandescent gas, is thoroughly established. Thanks to the spectroscope, that marvellous instrument by which we are enabled to ascertain the elements of which Sun, stars, and nebulæ are composed, we now know that the nebulæ are really gaseous, a point on which Herschel could merely theorise; and, what is even more important, we are enabled to trace the order of development. We see nebulæ and stars in all the stages through which our solar system has passed and will pass; and in the other planets of the solar system we behold the stages through which our Earth has passed and will pass. By a careful study of the heavens as they are to-day, we

[1] See Chapter XXV.

are enabled to read the past of our world and approximately to trace its future.

In the heavens we behold stars and nebulæ in every stage of evolution. First of all we have the widely diffused nebulæ of which the Orion nebula is a type. Next we have a more condensed nebula, such as that in Andromeda, and then the stage of the spiral nebula. These spiral nebulæ, of which there are many known in the heavens, are not gaseous; they are partially solidified and are already breaking up into subordinate centres of condensation, which will in course of time become planets or small suns. These larger nebulæ, like the Orion nebula and the great spiral, will in all probability develop into clusters of stars. The smaller nebulæ develop into stars similar to our own sun attended by systems of planets. By means of the spectroscope we are enabled to trace the development of these stars after they pass out of the nebulous stage. We have first the helium stars of a bluish-white tint, in which the element helium is predominant, which are largely gaseous in their constitution; next we have the white stars proper, in which the gases are not so widely diffused. Next we have the yellow stars, similar to our own sun, orbs in their prime, slowly but surely condensing. The next stage is that of the red stars, past the zenith of their careers, and slowly dying out. In this class are included many of the interesting objects known as variable stars, which are already becoming unstable in their light, just as a lamp flickers when it is going out. Lastly, we have the dark stars which are only known to exist by their influences on the bright ones. These orbs are extinct and dead suns, and they roll through space a solemn example of the goal to which our Sun among others is steadily moving.

The Earth, our own world, as we have seen, has developed from the condition of a little local condensation in the primitive nebula. From the same condensation has developed our satellite the Moon. It may be interesting to trace the various stages through which our Earth has passed as exemplified in the objects in the heavens around us. In the early stages of its history, "the Earth was without form, and void," as the Book of Genesis so simply and graphically tells us. In scientific language the Earth existed in the shape of an unshapely gaseous condensation in a chaotic nebula. This was the first stage of the Earth's existence. In the first "day" of Creation—the Bible tells us—"God said, Let there be light; and there was light." Independently science tells us the same. In passing we may note that we must not interpret the word "day" as meaning our terrestrial period of twenty-four hours. Such a period did not exist when "the Earth was without form, and void, and darkness was upon the face of the deep."

In those early times the Earth was self-luminous. Light came into existence as the nebulous mass slowly contracted. This light was in existence so far as the Earth was concerned long before the light of the Sun. Next we have the period when the Earth had solidified so as to admit of the existence of dry land, air, and water. Before this was an intermediate period when the transformation was being effected. Professor Lowell, in his recent work on "The Evolution of Worlds," traces very completely the evolution of the Earth from the gaseous state to its present condition. Not until the temperature of the Earth had fallen to a hundred degrees Centigrade in the outer regions of the atmosphere could clouds form, and not until the surface had reached the same temperature was it possible

for these clouds to settle on the surface as oceans. As Professor Lowell writes: "Reasoning thus presents us with a picture of our Earth as a vast seething cauldron from which steam condensing into cloud was precipitated upon a heated layer of rock, to rise in clouds of steam again. The solid surface had by this time formed, thickening slowly and more or less irregularly, and into its larger dimples the water settled as it grew, deepening them into the great ocean basins of to-day."

Later on the crust hardened, while the oceans were still boiling seas. These oceans, according to Lowell, must have produced a "small universe of cloud" all over the Earth's surface. After this the Earth began to sustain the lower forms of life. Vegetation, the flora of paleologic times, flourished, sustained by the heat of the Earth itself below the cloud-masses. So, again to quote Professor Lowell, "the flora of paleologic times, as we see both at their advent in the Devonian and from their superb development in the Carboniferous era, consisted wholly of forms whose descendants now seek the shade. These plants, grown to the dimensions of trees, inhabited equally the tropic, the temperate, and the frigid zones as we know them now. They grew right on, day in, day out. The climate, then, was as continuous as it was widespread."

The reason of the equality of climate all over the globe was the fact that the light and the heat of the Sun were shut off by the great cloud-masses and the heat was wholly supplied by the Earth itself. This produced the half light which suits the growth and the development of the tree-ferns. Hence the luxuriant vegetation of ancient days.

By and by the clouds dispersed. It was only then in reality that the year began, and that the seasons made their appearance. As the Sun was invisible, and its rays played

little part in the climate of the Earth, the annual revolution had no visible effects. But with the clearing of the sky, the outer universe came into existence, so far as the Earth was concerned.

An interesting point may be mentioned here, which Professor Lowell does not touch on in his book, and which is indeed seldom dealt with. It has been the fashion among many scientists to treat the record of the Creation in the first chapter of Genesis either as a story or as an allegorical history. But it is somewhat remarkable how close is the correspondence between the Biblical account and the latest scientific theory as developed by Professor Lowell. After detailing the bringing forth of vegetation consequent on the appearance of dry land, which followed the division of "the waters which were under the firmament from the waters which were above the firmament," the Biblical record says:—

"And God said, Let there be lights in the firmament of the heaven to divide the day from the night; and let them be for signs, and for seasons, and for days, and years. And let them be for lights in the firmament of the heaven, to give light upon the earth; and it was so."

Professor Lowell, who traces the Earth's history from a purely scientific standpoint, says quite explicitly: "Only with the clearing of the sky did the seasons come in, to register time by stamping its record on the trees. Before that, summer and winter, spring and autumn, were unknown." He also shows that before the clearing of the sky there was no climate. The downpours of rain from the "upper waters" must have been stupendous. There was imperfect recognition of day and night. Dull sombre days alternated with nights black as pitch. "The moment the Sun was let in, all this changed, though not

in a twinkling. The change came on most gradually. We can see in our mind's eye the first opening in the great welkin permitting the Earth its initial peeps of the world beyond. Eventually the clouds parted afresh and farther, and the Earth began to open its eyes to the Universe without."

The correspondence is complete between the account of modern science and the account of the ancient Biblical writer. So there need be no discrepancy between a belief in the evolution of the Earth, as described by modern science, and a belief in the accuracy and trustworthiness of the Biblical record.

Professor Lowell proceeds to trace the further development of our planet in what he calls the "Sun-sustained stage." The temperature of the oceans fell, and a totally different variety of animals and plants came into being. The oceans were inhabited by fishes in the earlier days; but after the clearing of the skies the land became peopled with different varieties of animals and reptiles. Then came the development of vegetation, depending on the change of the seasons; next followed the coloured flowers. The Earth became beautiful, clothed with all the verdure of the flowers; and this sudden development of beauty was due to the fact that the Sun had become the dominant factor in the Earth's organic life. The Sun, so far as the Earth was concerned, did not come into existence until after the original appearance of life on the Earth. And the celestial bodies in general were invisible until the fourth "day" or period of Creation.

Jupiter is a much larger planet than ours, and at a much earlier stage of its evolution. Therefore a careful study of it throws light on the history of the Earth. As already mentioned, after the invention of the telescope it

was found that the visible surface of Jupiter was diversified by numerous markings known as belts. As astronomical observation progressed, it was found that these were belts of dense clouds, so dense that it is impossible to see through them the real surface of Jupiter. It was originally supposed by astronomers that these clouds were of the same nature as our terrestrial clouds raised up by the heat of the Sun. But it has been conclusively shown that this is impossible. The atmosphere of Jupiter is much more cloudy than our own, and yet the planet is many times farther from the Sun than the Earth. The clouds are certainly raised by heat, but not by Sun heat. They are raised by the intense heat of the planet itself, which does not permit the vapours to settle down as oceans, but raises them into the atmosphere, in which they float in the form of cloud belts. Here, then, we have a world in a condition similar to that of our Earth before the accomplishment of the work of the third day of Creation, and consequently before the work of the fourth day, when the Sun, Moon, and stars appeared. Jupiter will not reach its "fourth day" until the clouds roll away and the glories of the outer Universe are visible from the surface of the giant planet. Jupiter is the best example of a planet in an earlier state of development than our Earth. Other examples may be cited in Saturn, Uranus, and Neptune. Each of these is much larger than the Earth, and each of these appears to be in a condition of great heat and at present quite unfitted to be the abode of living creatures.

In Venus we have a planet in the same stage of planetary life as the Earth, because it is of the same size. In Mars we have a stage further. This planet is smaller than the Earth, and has consequently run more swiftly through the stages of its evolution. On Mars, planetary old age has

set in. The oceans are all practically dried up; and their place has been taken by marshy tracts of vegetation; and the atmosphere is very rare.

In the Moon, our own satellite, we have the final stage of planetary life. The Moon is a dead world. It has practically no atmosphere, and the oceans which once must have existed on its surface have completely disappeared. The surface of the Moon is a succession of very mountainous regions succeeded by flat grey barren plains, which are supposed, owing to their low level, to represent the old ocean beds of the Moon, which in earlier days were filled with water. The Moon rolls through space a dead world, an indication of the future which awaits our own planet.

Just as in a garden, where we behold flowers in different stages of development, and may by the study of these indicate the life-history of a given flower, and read its past and future; just as in a forest, by noticing the various objects, from the tender shoot to the magnificent full-grown tree, we are able to tell the past and future of any member of the group; so in the heavens, by noting all the different stages of star and planet life, from the diffused nebula to the dead world and the dark star, we are enabled, with remarkable accuracy, to read the past and future of our own dwelling-place, the Earth. To quote the reverent remark of Kepler, we are permitted to think the thoughts of God after Him; we are enabled to trace in a partial manner the marvellously beautiful method by which the Creator has called into being this magnificent Universe in which we live; and we realise in a new light the meaning of these words, "For My thoughts are not your thoughts, neither are your ways My ways, saith the Lord: for as the heavens are higher than the earth, so are My ways higher than your ways and My thoughts than your thoughts."

CHAPTER XXV

THE ROMANCE OF THE TIDES

THE ceaseless ebb and flow of the ocean has from the earliest ages attracted the attention of all thoughtful observers of Nature. The waters of the sea are never at rest. No sooner is the ebb reached than the flood begins; no sooner is the flood reached than slowly but surely the waters begin to ebb. Thus for ages, ever since the world was first formed, the waves of the ocean have beaten on the shore. And since scientific speculation and research began, the cause of the tides has attracted the attention of men of science.

The study of the tides belongs to the realm of astronomy. To many this statement doubtless comes as a surprise, yet it is strictly true. The tides are due to the gravitational pull on the Earth of two celestial bodies, the Sun and the Moon; and the waters, as the most easily pulled portion of the Earth, are consequently the parts which are most displaced in position.

The Moon is chiefly responsible for the tides, although the Sun plays a smaller part in the phenomenon. Notwithstanding its vast superiority in size, the Sun is so far away that its pull on the waters is much less than that of the insignificant Moon. Our satellite plays the chief part in raising the tides. But the Sun certainly makes its influence felt. Every month, there are two spring tides and two neap tides, as they are called. The word "spring

tide" is somewhat misleading, for a spring tide has nothing whatever to do with the season of spring. Spring tides, the highest tides of all, are due to the fact that at the time the Moon is either new or full. The Sun and Moon are both exerting a pull in the same straight line, and their combined force raises a higher tide than usual. The lowest tides, or neap tides, take place when the Moon is at first quarter or last quarter. At these periods the Sun and Moon are tending to pull the waters in different directions, and the resulting tide is lower than the average.

The tide which is raised on the Earth is made up of two parts—the direct tide, the tidal wave on the portion of the Earth towards the body which raises it, and the opposite tide on the other side of our planet. As the Earth rotates on its axis from west to east, the watery bulge, as one astronomer calls the heaping-up of the tides, appears to travel from east to west as a tidal wave twice in twenty-five hours, or, to be more correct, 24 hours 48 minutes, the time required by the Earth to make a complete rotation relative to the Moon.

Of course the waters of the ocean do not travel round the Earth. Only the form of the wave travels from east to west. This wave originates in the deep waters of the Pacific ocean and travels westward, its speed varying with the depth of the ocean. The deeper the waters, the faster the velocity of the wave. As the wave is in motion, it meets other waves, so the resultant wave is not so simple as might be supposed. In about twelve hours, however, the main wave reaches New Zealand, and in about thirty hours it arrives at the Cape of Good Hope. Here it joins two other waves, the tide in the Atlantic off the African coast and a reversed wave, which has moved into the Atlantic from the other side of Cape Horn. The resultant wave travels

through the Atlantic with a velocity of about seven hundred miles an hour.

In the deep oceans there is little bodily motion of the waters. The waters merely rise and fall with a velocity varying as their depth. It is otherwise, however, near the coasts. At the mouths of great rivers the waters move bodily up the river beds; similarly on the sea-shore, as indeed we know well from experience. In the mouths of some rivers the result of the rising tide is very picturesque. In the case of the Seine, the tide surmounts the current of the river and rolls with increasing velocity up the river bed. This phenomenon is known as the *bore*. At Caudebec, on the Seine, this phenomenon is especially noticeable. The following lengthy notice by the master-hand of Flammarion is worthy of quotation, so well does it explain this remarkable spectacle :—

"On the day and the hour indicated, the wharf, shaded with perennial trees and splendid walks, is crowded with spectators. These are the inhabitants who are never tired of the grand spectacle of the river transformed, and strangers who come from far to enjoy and to study it. For a long time before the arrival of the flood impatient eyes search the horizon, and the less experienced think every moment that they see it beginning at the extremity of the bay which forms this bend of the Seine. A low murmur announces its approach when it is still at a distance of several miles. The vast sheet of water advances rapidly under a radiant sun ; in the midst of a verdure which a zephyr scarcely stirs, there are all the motions, all the agitations, all the fury, of a tempest-tossed sea. Very soon the spectacle changes to become grander and more singular still. The enormous wave which marches at the head of the tide swells, rises, stands up ; it bursts of a sudden, and its summit falls with

a crash ; an immense roll is formed and unfolds itself, sometimes from one end to the other ; it is a cascade which moves, which runs and remounts the river with the speed of a galloping horse. The flood runs along like a wall of foam, overthrowing all obstacles and rearing itself up each instant like a gigantic plume, to fall again quivering on the bank, which it deluges. The ground sometimes trembles under the feet of the spectators, who see, in less time than it takes to describe it, the boiling mass passing on and pursuing its ungovernable course."

In England there is another famous tide which rushes up the Bristol Channel with a tremendous force. The greatest tide in the world, however, is to be seen at the Bay of Fundy. Here the Atlantic passes into a lengthy channel with sides which gradually converge. As the water rushes up this channel it becomes heaped into a great volume, of which the height at the spring tides is over fifty feet. In mid-ocean the rise and fall of the waters is much less than round the coasts. The island of St. Helena, for instance, is washed by a tide of which the height is only about three feet.

Wonderful are the phenomena of the tides at the present time. Mighty are the forces possessed by the rolling waters, but a scientific study of the tides reveals facts more remarkable than those which we have mentioned, truths vastly more astounding which give us a glimpse into the past of our world and enable us to forecast its future. The mathematical study of the tides was commenced by Sir Isaac Newton, who confirmed by his work the vague notion of Galileo and Kepler, that the tides were caused by the Sun and Moon. Laplace, the famous French mathematician, completed Newton's investigation, and worked out mathematically the complete

theory of the tides. In more recent times the mathematical work of these investigators has been supplemented by that of Professor Sir George Darwin of Cambridge, whose researches have given us a glimpse into the shadowy past and the mysterious future.

Darwin found in the course of his investigations that the constant tidal wave, persisting throughout the ages, acts on the Earth as a brake acts upon a machine. It tends to retard the Earth's motion of rotation on its axis. In other words, the tides tend to increase the length of the day by slowing down the rate at which our world is spinning.

It will be noticed that, so far as we know, this is the *tendency* of tidal action. In the history of mankind, the day has not lengthened by even a small fraction of a second, and we do not know from experience that this constant tidal action is wearing down our planet's speed. Nevertheless, mathematics have proved this to be the case. Millions of years are required for the results of these forces to become manifest; so it is not surprising that the length of the day has not changed appreciably in the course of the few thousand years during which the human race has lived on this planet, and the few hundred years in which astronomers have determined the length of the day with any approach to accuracy.

Not only is the day becoming longer; the Moon's distance is becoming greater, and its period of revolution is increasing in length. At the present time our day is about twenty-four hours long, and our month about twenty-seven days. Darwin's researches show that with the constant friction of the tides on the Earth the day will be lengthened at a more rapid rate than the month, and in the distant future the day and month will coincide

in length, both lasting for fifty-five of our present days. The Moon will revolve round the Earth in exactly the same period as our planet requires to rotate on its axis, so that the two bodies will perform their revolution round the Sun as if united by a bar, turning the same face to each other. This is the future which the continuous action of the tides holds in store for our planet.

Not only does a study of tidal action give us a glimpse into the future of the Earth and the Moon. It also enables us to read the past, when the Earth was in a plastic condition and tremendous tides were raised, not in the oceans, but in the semi-liquid crust of our planet in the early stages of its history. According to Darwin, the Earth in the remote past was rotating on its axis in a very short period, probably between three and five hours. Reasoning backward, we see that the Moon must have been much nearer to the Earth at that time than it is now, and was probably revolving round its primary in a period identical with that of the Earth's rotation. The Earth and the Moon, then in a gaseous or semi-gaseous condition, must have been revolving almost in actual contact. This was a state of affairs which could not continue. The condition of the Moon resembled that of an egg balanced on its point. The Moon must either recede from the Earth or fall back on its surface; and had the month been even one second shorter than the day, our satellite would have become united to the terrestrial globe. Here interposed the tide raised by the Sun in the plastic materials of the two bodies, and the action of this tide caused the Moon to recede slowly from its primary until it reached its present distance of 238,000 miles.

Now the fact that the Earth and the Moon were at

this distant epoch almost in contact, suggests that they were originally in contact and formed one body. The Moon originally formed part of the Earth, which in consequence of its very rapid period of rotation—between three and five hours—and also owing to the interference of the solar tide, split into two; and of these portions the smaller now forms the Moon. The matter which now forms the Moon may have been detached from our Earth as a whole or in parts; but it is almost certain that it was detached from the Earth owing to the rapid rotation of our planet, which made a rupture inevitable.

A suggestive speculation, due to Professor W. H. Pickering, the well-known American astronomer, is worth mentioning here, so full of interest is it to the Earth's inhabitants. Following up Darwin's work, Professor Pickering considers that "it will be of interest to determine if possible from what part of the Earth the Moon originated."

"When," says Professor Pickering, "the Earth-Moon planet condensed from the original nebula, its denser materials collected at the lower levels, while the lighter ones were distributed with considerable uniformity over its surface. At the present time we find the lighter materials missing from one hemisphere. We find a large mass of material now up in the sky, which, it is generally believed by astronomers, formerly formed part of the Earth, and the density of this material we find to be not far from that of the missing continents. From this we conclude that this mass of material formerly covered that part of the Earth where the continents are lacking and which is now occupied by the Pacific Ocean." Professor Pickering also finds a connection between the volcanoes of the Pacific region and the volcanoes of the Moon. This,

it is to be remembered, is merely a speculation, with, however, "the balance of evidence" on its side. It certainly gives a new interest to the study and contemplation of the Moon, when we remember that the silver orb which illuminates our evening skies is formed of materials which once filled the bed of the greatest ocean on the globe.

Another interesting fact disclosed by Darwin's studies is that, just as the tides raised by our satellite tend to retard the rotation of the Earth, so the tides which the Earth raises in the Moon have the same effect. There is, however, this important difference. There is no water on the Moon. The tides raised by our planet on the Moon did their work ages ago, when our satellite was in a plastic or semi-liquid condition. The superiority of the Earth over the Moon in the matter of size compelled the Moon to rotate on its axis in the same period as it requires to revolve round the Earth.

We may now briefly sum up the conclusions to which astronomers have been led. First, we have a globe of molten matter, now known as the Earth, turning on its axis in a very short period. This very rapid rotation, assisted by the tides raised by the Sun in both bodies, caused the rupture of the Earth into two bodies, and the smaller now forms the Earth's satellite, which we call the Moon. As a result of continual tidal action, the rotation of the Moon was retarded, and it was forced farther and farther from our planet until it reached its present position. Slowly but surely the action of the Moon in raising the tides of the ocean is slowing down the rotation of the Earth on its axis, and in the distant future—probably long after the Earth is uninhabitable and dead—our planet will require fifty-five of its present days to rotate on its axis.

What of the time which has elapsed since the Moon

was separated from the Earth? This is a matter of some uncertainty, and Professor Darwin's studies place the period of disruption at about fifty-seven millions of years ago. The mind falls back astounded at such a statement, and we can only repeat with deeper reverence the familiar words — "A thousand ages in Thy sight are but as yesterday when it is past."

When on a moonlight evening we stand on the sea-shore and behold the ceaseless ebb and flow of the ocean, with the sound of the waters breaking on the rocks, we have brought to our minds overwhelming thoughts. There is the silver Moon which is constantly operating on our planet, and which, by means of this ceaseless ebb and flow which its action causes, is slowly but surely lengthening our day and slowing down our world. And by a study of the tides we have reached the remarkable conclusion that the same silver Moon, our planet's faithful attendant, has been constantly travelling farther and farther from the Earth since that period when it separated from our world; and that period we have calculated as fifty-seven millions of years ago. Truly, of all the wonders of modern astronomy, there are few more astounding than the romance of the tides!

CHAPTER XXVI

LIGHT AND ITS MYSTERIES

THE foregoing sketch of the Universe, from the Earth itself to the systems of stars glimmering on the brink of Infinity, serves to show that astronomy is, after all, no dry, uninteresting subject, but truly a fascinating and romantic study. Marvellous facts concerning the Universe have been brought to light. Suns and planets have been weighed and measured, invisible bodies found by their influence on bright ones, comets traced on their journeys away out into the outer spaces. In short, on all sides, the astronomer has been the victor in the contest with the unknown. Although, as Laplace said when he was dying, "what we know is but little, what we do not know is immense," it is truly remarkable how much knowledge of the Universe has been gained by patient observation and careful calculation from observation.

How, then, are we enabled to make observations of the celestial bodies? Our ability is owing to the fact that we see them—that the light rays from these bodies reach our Earth and make known their existence to us. Light therefore bears to us the secrets of space. Mention has been made incidentally in previous chapters of many of the characteristics of light, and of its velocity; but, so far, nothing has been said of its real nature. Light emanates from the Sun and stars. The light from the Sun falls on

our world. We are bathed in it, so to speak. Everything on the Earth more or less reflects the sunlight. Then it likewise falls on the planets, and like the Earth they reflect it back, and shine by borrowed sunbeams. The stars all shine by their own inherent light, and send it through the depths of space for billions of miles. Light is a vibration sent from the Sun, stars, and nebulæ across the substance known as ether, which fills all space. But light does not travel instantaneously. It was discovered in 1675 by Roemer, a Danish astronomer, from observing the eclipses of the satellites of Jupiter—that these eclipses are seen later when the Earth is at a greater distance from Jupiter, and earlier when it is at a less distance. He therefore concluded that light requires time to travel. His brilliant idea was confirmed by a succession of illustrious astronomers throughout the centuries, and they all agree that the velocity of light is 186,000 miles per second. Light, then, does not travel instantaneously. On the Earth, for all practical purposes, it does so. It reaches us from the Moon in a second and a half. From the Sun it travels in eight minutes. When we witness, say, a great cataclysm beginning on the Sun, we may know that it commenced eight minutes ago, and that the light has been travelling over the ninety-three millions of miles which separate us from the Sun in the interval.

Light, then, travels at the enormous velocity of 186,000 miles in one second of time. It crosses the diameter of the solar system in eight hours. It takes four years to reach us from the nearest of the stars. Sirius, the brightest star of the sky, is at a still greater distance, for light requires eight years to reach us from that orb. Again, light takes no less than 200 years to reach us from Arcturus, one of the brightest stars in the sky. We can

see stars whose light left their surfaces thousands of years ago—stars which, for all we know to the contrary, may be dead and extinct to-day; but their light has been travelling through space for all these centuries. As an example, we may take the famous new star in Perseus, which was discovered in 1901 by Dr. Anderson. The outburst did not take place in the year 1901, which was merely the year that the light was first seen on the Earth. Astronomers calculated that the outbreak must have taken place about the year 1603, in the reign of King James VI. of Scotland. The light from the new star was speeding across the depths of space for three hundred years before it reached this Earth of ours. The light which flashed on the Earth from Nova Persei conveyed to the Earth intelligence of a catastrophe which took place three centuries ago.

This, too, is by no means an extreme case. Light takes several thousand years to reach our Earth from the boundaries of the Universe. The various calculations may not be scientifically accurate, but they give us an idea of the vast distances of the fainter star-clouds of the Galaxy. We do not see the stars as they are; we see them as they were in some cases centuries ago.

Mr. Gore, as mentioned in a previous chapter, has calculated the possible distance of the supposed external universes. Of course these external universes have never been seen and we cannot be certain of their existence, but, reasoning from probability, astronomers have good grounds for believing in their existence. Mr. Gore's calculation places the nearest of these universes at a distance so vast that light takes ninety millions of years to reach us from its inconceivable distance. The mind is overwhelmed with such an idea. We cannot comprehend ninety millions of

years; and yet this is only the nearest of these universes, and if space is infinite there must be more. There will be an infinite number of such universes scattered throughout an infinite Cosmos. Truly astronomy—at least modern astronomy—is the science of infinity and eternity. What a vast difference there is between the magnificent sweeping conceptions of modern astronomy and the primitive and crude ideas of the ancient astronomers, who thought that the Earth was the centre of the Universe and that the stars were little lamps suspended above the clouds to light up our planet on a dark night!

A study of the motion of light and its consequent effect on the heavens leads us to some interesting conclusions. The stars are at different distances, and consequently light takes longer to reach us from some than from others. For instance, light travels from Sirius in eight years and from Arcturus in over two hundred years. The result of this is that we never see the stellar system as it is at present or even as it was at any given time. Each of the stars which we see is at a particular distance of its own. One may appear to us as it was twenty years ago, another as it was a thousand years ago. We see what we may call the "ancient light" of the various stars. Now let us suppose that astronomers were able to construct telescopes large enough not only to enormously magnify the stars but to show the planets which are revolving round them, and the events which are happening on the surface of these planets. Could we observe these planets we should not see the events which are happening at this moment, but the events of years ago, because light takes time to travel. In the case of a planet revolving round Sirius we should see not the events of the present time but the events of eight years ago. If there are inhabited planets revolving round Sirius

then their light is combined with the blaze of their primary. Could we disentangle the rays and see these planets and their inhabitants we should behold what was enacted on their surface eight years ago.

We may now invert the idea and apply it to our own Earth. As an American astronomer has expressed it, "the light from every human action performed under a clear sky is still pursuing its course among the stars." Suppose that in some of the planets revolving round the stars there exist astronomers who have built telescopes large enough not only to see the planets revolving round the Sun, but to see the Earth, its various nations and peoples, and what is going on on its surface. At the distance of the nearest star our Sun is reduced to a star of the second magnitude, and all the planets are lost in the solar glare, still the idea is correct. The astronomers on planets revolving round Sirius would see the Earth as it was eight years ago. Similarly the people on planets moving round the Pole Star would see the Earth as it was forty-nine years ago. Likewise, on Arcturus the Earth would appear as it was two hundred years ago. Supposing that from these stars and planets not only the Earth but the countries on its surface, even the little country called Great Britain, could be seen, the inhabitants of some of them would only now be witnessing the Battle of Bannockburn; others further away would now behold the Battle of Hastings. Still further away others would see our country inhabited by wild animals.

What does all this teach us? It teaches us that there is no such thing as the past. The events of ancient history, for instance, are past so far as we are concerned, but they are not past in reality. The light from them is still speeding onwards from them through space. As

Flammarion expresses it: "The progressive motion of light carries with it through Infinity the ancient history of all the suns expressed in an eternal present. Events vanish from the place which brings them forth, but they remain in space."

Of all the romances of astronomy this is the most romantic. Yet it is all strictly true. It is obvious that we are now treading on half explored ground, for we have neither the ability nor the instrumental power necessary for us to realise the truth of Flammarion's statement. For instance, we only measure time in days and years because we live on a little planet revolving round a star. Away out in space there is no such thing as a period of time, because there is no method of measuring time. And when we cannot measure time we cannot think of a past; everything is present. The whole subject is overwhelming and beyond our conception. With our limited understandings we cannot grasp it in its entirety. In our present existence we only see these marvels "through a glass, darkly." Still, here again, we find the oldest of the sciences aiding us in our comprehension of religion, and we at last grasp the meaning of the deep saying of Carlyle that to God there is neither past nor future, but all is an eternal Now.

CHAPTER XXVII

HOW TO KNOW THE STARS

PERHAPS no one can really appreciate the romance of astronomy without being familiar with the brighter stars and the principal constellations. As Mr. E. W. Maunder puts it: "How great an interest is given to any object by the fact that we know its name. Take some town children out into the country, and set them to gather wild flowers, how instantly they ask their names." It is the same in the case of the stars. When we look at the heavens on a clear night and behold apparently countless points of light, we are lost and overwhelmed with the number of the stars and the complexity of their distribution. One star seems much like another, and we look away from the sky again with neither interest nor curiosity. But if we are told that such and such a star is Aldebaran, and such and such is Sirius, our interest is aroused, and we naturally desire to trace out the star groups in the heavens and to identify the stars for ourselves.

"But," asks the would-be astronomer, "how is it possible for me to learn the star names and trace the constellations without being taught?" Carlyle lamented in his old age, "Why did not somebody *teach* me the constellations and make me at home in the starry heavens?" But in reality no one requires to be taught the constellations. Every one can best learn them for himself. At the outset, it is true, the task seems impossible of attain-

ment, and some of the hints given in astronomical books only make the task seem more gigantic. When we are told to draw imaginary lines through such and such stars of the Plough and these will lead us to such and such stars in Leo, and will form triangles and quadrilaterals with such and such stars in Cepheus, we feel baffled with the magnitude of the task, and many would-be astronomers fall back in despair and become star-gazers pure and simple.

Now this geometrical method, as we might call it, is all very well after we have acquired a knowledge of the chief constellations ; it will then aid us in identifying the various stars of these constellations. But it is open to very serious objections when we are studying the heavens for the first time. Instead of this method there is another which, for want of a better term, we may call the pictorial method. The beginner should first possess himself of a revolving planisphere, which shows the heavens at the various seasons of the year, and which is of a convenient size to be taken out of doors. He should then decide which part of the heavens he wishes to consider, and having selected, say the Southern aspect, he should adjust the planisphere to the day and hour and examine it with the aid of a lantern. He will be surprised to find that he can trace without difficulty in the heavens the forms which he sees on the planisphere and the names of which he learns. He sees, for instance, on the planisphere a particular group in the form of a cross high up, and named "Cygnus." When he turns his gaze to the heavens, there he can trace this form without difficulty. Where a few minutes ago he could only see an irregular mass of stars, he now sees a star group with a distinct form and its own individuality. Similarly the observer will pick up other groups in the same manner. No attempt should be made to force the recollection of the

groups, but the observer should return night after night to the same part of the heavens. He will be surprised to find that he is beginning to know the constellations without any effort; the configurations are becoming familiar to him, and, after a few nights' comparison of the heavens and the planisphere, he will be able to identify Cygnus, Aquila, &c., without the aid of the planisphere. In this manner the observer may in the course of a few months learn all the various constellations. The names, too, of the brightest stars are marked in the planisphere, and he will thus unconsciously learn them also. For instance, he will see that one of the stars in Lyra is very bright. Looking at the planisphere he will see that it is thereon designated by a special name, "Vega"; and thus a knowledge of the brighter stars individually is easy.

Many are content with a knowledge of the constellations and bright stars, but it is well to be familiar with most of the stars of the second magnitude as well, and also some stars of the fainter magnitudes. For this purpose, of course, the planisphere is of no use. The observer should consult some star maps or atlas of the stars. But he should be particularly careful in his choice of star maps. By all means let him avoid those on which are represented what are known as "the constellation figures." In such maps we find the Plough represented by the figure of a bear dotted with stars, Cygnus by a star-spangled swan, Orion by a hunter marked with stars. The stars are all inserted and named, but they are lost and confused through the introduction of the constellation figures. These figures are very interesting to the antiquarian and to the astronomer who studies closely the beginning of the science, but they are utterly out of place on such star maps. They existed and exist only in the imaginations of men and

have no counterpart in the heavens. Whatever maps the would-be astronomer uses, he should use maps on which only the actual stars are marked. Various excellent maps could be mentioned. In "A Handbook and Atlas of Astronomy," by Mr. William Peck, Astronomer to the City of Edinburgh, there is a good series of charts respecting regions in the heavens which should be of much use to the observer. If the observer, however, wishes to study not regions but individual constellations, he should at once possess himself of Mr. J. E. Gore's excellent guide entitled "Star Groups." This latter method of learning the individual stars is really the best. Once the form of the constellation is mastered with the aid of the planisphere, the observer is familiar with the constellation's form and can study each star group individually. At this stage of his knowledge he will find Mr. Gore's book of the utmost value. The constellations are represented on separate maps and there are no constellation figures, nor even any degees of measurement. The stars are shown in white on a black background, and with the aid of this book and a lantern the observer will not only have mastered the constellations, but will have gained sufficient knowledge of the heavens to enable him to begin astronomical observation on his own account.

Nothing has been said here of the identification of the planets, and nothing need be said. The student will find no difficulty in recognising the planets; he will soon learn to recognise the dull yellow glare of Saturn, the soft golden glow of Venus, the steady shining of Jupiter, the ruddy beams of Mars. He may even succeed in catching a glimpse of the elusive wanderer, Mercury, "the sparkling one," on some evening or morning when the horizon is clear and the planet well placed for observation.

HOW TO KNOW THE STARS

As mentioned in a previous chapter, with the changes of the seasons new star groups appear, old star groups disappear. In the South we behold the stately procession of the stars nightly across the skies. Leo, Virgo, Gemini in spring; Boötes, Scorpio, Hercules in summer; Cygnus, Aquila, Cetus in autumn; Orion, Taurus, Canis Major, Perseus in winter. While the Plough and the Cassiopeia, and the other northern stars surrounding the Pole Star circle slowly round as the months go by. As the seasons advance the reappearance of a familiar constellation lends a new charm and interest to the evening walk. As Mr. Maunder has well said, the work of learning the stars "has a charm of its own. The silent watchers from heaven soon become each a familiar friend, and to any imaginative mind the sense that he is treading the same path as that traversed by the first students of Nature will have a strange charm."

Once the observer has learned the constellations he is able to commence systematic observation on his own account. Even with the unaided eye he may accomplish work which will at least afford him pleasure if it does not add to the sum of knowledge. With a field-glass we may make many interesting observations, while quite a number of celestial spectacles are open to the observer possessing a telescope of two inches aperture.

In the following list an account is given of the chief objects of interest in the chief constellations in alphabetical order—

Andromeda.—The most interesting object in this constellation is the great nebula. It may be glimpsed with the unaided eye, and is easily seen with a field-glass. In a 2-inch telescope it is a very fine spectacle. The chief stars are Alpha, Beta, and Gamma of the second magnitude, and Delta of the third.

Aquarius.—One of the Zodiacal constellations and inconspicuous. Its chief stars are Alpha and Beta of the third magnitude, Delta and Zeta between the third and fourth.

Aquila.—A very striking group. Well seen in summer and autumn. The chief stars are Alpha (Altair) of the first magnitude, and Beta and Gamma of the third. The three are on a line. The star Eta is a short period variable with a period of seven days. It is easily followed with the unaided eye. The Galaxy is very brilliant in this constellation.

Aries.—A small compact constellation. The brightest stars are Alpha and Beta of second and third magnitude respectively. Aries is the first of the Zodiacal constellations.

Auriga.—One of the most notable of the constellations and a good group for binocular observation. The brightest stars are Alpha—the brilliant Capella—of the first magnitude, and Beta of the second.

Boötes.—A straggling constellation which Mr. Maunder believes to resemble the much more striking group of Orion. The brightest star is Arcturus, or Alpha Boötis, of the first magnitude. Delta shows in the field-glass as a double star.

Cancer.—This is the smallest and most inconspicuous of all the Zodiacal constellations. The only striking feature of the group is the cluster known as Præsepe or the Bee-hive. It is visible to the unaided eye as a nebulous object, but the least optical aid shows it to be a group of stars.

Canes Venatici.—This is a very small constellation containing only one conspicuous star, Alpha, known otherwise as Cor Caroli.

Canis Major.—This group of stars lies too low down to be seen to full advantage in this country. Nevertheless it is a very fine celestial spectacle. Alpha, or Sirius, is the brightest star in the sky. It forms with Betelgeux in Orion and Procyon in Canis Minor an equilateral triangle. Although the study and identification of the stars on the principles of lines and triangles is, generally speaking, to be avoided, this is a figure so regular, so massive, that no one can mistake it, and it is useful to remember the names of the three stars which form it. The brilliance of the three and the dearth of brightness within the figure make it a majestic feature of the heavens. The following

ancient rhyme quoted by Admiral Smyth should assist the beginner in remembering these stars—

> "Let Procyon join to Betelgeux
> And pass a line afar
> To reach the point where Sirius glows,
> The most conspicuous star,
> Then will the eye delighted view
> A figure fine and vast,
> Its span is equilateral,
> Triangular its cast."

Canis Minor.—A very limited group. Its brightest star is Procyon, of the first magnitude.

Capricornus.—This constellation is a good field for the binocular. Alpha of the third magnitude is a visual double star and is well seen with the binocular. It is not a true double star, as the two stars are travelling in different directions, and merely appear to be connected because they happen to lie in the same line of vision.

Cassiopeia.—No one can fail to recognise this constellation, shaped like the letter W, which is on the opposite side of the Pole Star from the Plough. It is a good binocular field. The region round the star Gamma is a particularly interesting one. The star Alpha is slightly variable in light.

Cepheus.—A less conspicuous group than the former. Viewed with the binocular, however, there are some fine star-fields. A notable triangle is formed by the stars Delta, Zeta, and Epsilon. Of these Delta is a variable star from the third to the fourth magnitude, with a period of 5 days 8 hours. In the same constellation is Mu Cephei, the reddest star visible to the unaided eye. It is of the fourth magnitude, and was called by Herschel "the Garnet Star." It is a striking spectacle in the binocular.

Cetus.—A long straggling group somewhat difficult to follow. Beta, the brightest, is of the second magnitude. The most notable star in the constellation is Omicron, known as Mira, "the wonderful star." It is a notable variable with a period of 331 days. At maximum its variation may be easily followed by the unaided eye.

Corona Borealis.—There is not the slightest difficulty in identifying this constellation. Its name, "the Northern Crown," suits it exactly, and, from its crown shape, is easily identified. Its brightest star, Alphecca, of the second

magnitude. It is a good field for the binocular. In this constellation appeared the "blaze star" of 1866.

Corvus and Crater.—These are two small insignificant constellations seen in the South in the spring-time. They present little of interest to the beginner.

Cygnus.—This is one of the finest constellations in the entire heavens. The Galaxy is here particularly rich, and fine fields are within the reach of the binocular. Round Alpha there is a remarkable arrangement of the stars, and round Gamma there is one equally striking. Beta is a magnificent double, seen to advantage in a 2-inch telescope; the component stars are yellow and blue. It is interesting to identify the faint stars. One of these, 61 Cygni, is easily visible to the unaided eye. The constellation's most striking feature is the long cross formed by the stars Alpha, Beta, Gamma, Delta, and Epsilon. Of these Alpha is the brightest and Beta the faintest.

Draco.—A long, straggling northern constellation. It does not offer many attractions to the beginner.

Eridanus.—Another straggling group seen in the South in winter. Its brightest star is invisible in the northern hemisphere.

Gemini.—This is a very fine group easily identified. Its brightest stars are Pollux of the first magnitude and Castor of the second. A little north of Eta is a star cluster just visible to the unaided eye. Zeta is a well-known variable easily within the reach of the beginner.

Hercules.—The chief feature of this group is the famous star cluster. It is fairly well seen in a 2-inch telescope.

Hydra.—Like Draco and Eridanus this is a straggling group. In the words of Mr. Maunder it "begins close to Procyon under Cancer, and it stretches below the Zodiacal constellations of Cancer, Leo, and Virgo and the greater part of Libra. It has few bright stars and these grouped in easily remembered figures; and the great reaches of arren sky it includes seem referred to in the name given to its brightest star, Al Fard, the solitary."

Leo.—This is a Zodiacal constellation easily identified. Its brightest stars are Regulus of the first magnitude and Denebola of the second. Its most notable feature is the well-known Regulus. In this constellation is the radiant point of the November meteors.

Libra.—A Zodiacal constellation, but very inconspicuous.

Lyra.—One of the most compact and easily identified groups. Vega is the brightest star and a striking object. Beta is a well-known variable and easily followed by the unaided eye.

Ophiuchus and Serpens.—These two groups are so intermixed that they may be treated as one. They are among the most difficult of all the constellations in the entire heavens. Serpens presents some good binocular fields.

Orion.—By common consent Orion is the most magnificent of all the constellations. Betelgeux and Rigel are the two chief stars. Rigel is generally the brighter, but Betelgeux is a variable and at times surpasses Rigel. The red tint of Betelgeux is very noticeable and contrasts with the bluish white light of Rigel. The great nebula in Orion is just visible to the unaided eye. A binocular shows it, and it is seen to advantage in a 2-inch telescope, through which it is a striking and awe-inspiring spectacle. Orion has two stars of the first magnitude, Alpha and Beta (Betelgeux and Rigel), and five of the second, Gamma, Kappa, Delta, Epsilon, and Zeta. The three latter forming the "belt of Orion."

Pegasus.—This is a very notable constellation and a conspicuous feature of the autumn skies. The "Great Square" is formed by four stars, one of which, however, belongs to the neighbouring constellation Andromeda. The square is all the more striking on account of the dearth of stars within.

Perseus.—To the beginner Perseus is perhaps the most interesting constellation. The brightest star, Alpha (Mirfak), is situated in a magnificent region. Seen with the field-glass, there is a curve of stars with Mirfak at the centre. Seen with the telescope, the scene is even more striking. Near to the star Chi Persei is a magnificent cluster, which can be seen with the binocular, and is a magnificent object in a 2-inch telescope. Beta Persei, or Algol, is one of the most remarkable variable stars in the sky. All the variations are within reach of the unaided eye.

Pisces.—This is a constellation of faint stars, of little interest to the beginner.

Piscis Australis.—This constellation may just be glimpsed on a clear autumn night, when the brightest star Fomalhaut of the first magnitude is to be seen glimmering on the horizon.

Sagittarius.—A star group deeply immersed in the Galaxy which well repays observation with the binocular.

Taurus.—This is a constellation of the utmost charm and beauty. In a field-glass its beauties are specially evident. The cluster of the Pleiades is particularly striking in a binocular, as is also the Hyades, the group surrounding Aldebaran (Alpha Tauri), the brilliant red star.

Of these two clusters the Pleiades is by far the finest. Six stars are to be seen by persons of average eyesight, but with a binocular many more are to be counted.

Ursa Major.—This famous constellation is known to all, at least its chief stars which form the Plough. The stars Alpha, Beta, Gamma, Epsilon, Zeta, and Eta are of the second magnitude, and Delta of the fourth. Zeta is a double easily seen with the unaided eye. The two stars are known as Mizar and Alcor. In a small telescope it is a striking spectacle.

Ursa Minor.—This group is notable as it contains the Pole Star of the second magnitude.

Virgo.—A conspicuous constellation visible in spring. It is shaped like the letter Y. Spica, the brightest star, is of the first magnitude.

Very little can be done in the study of the planets with the unaided eye or the binocular ; but the phases of Venus, the satellites of Jupiter, and the mountains of the Moon are all within reach of a small telescope of one or two inches in diameter.

CHAPTER XXVIII

TELESCOPES AND OBSERVATORIES

THE greater part of our knowledge of the science of astronomy is due to the marvellous instrument known as the telescope, which, by magnifying the celestial bodies, enables men to study them at much less than their actual distance. Before the invention of the telescope there was certainly a science of astronomy, but it was chiefly a science of statistics—star-catalogues, star-positions, planetary positions, and apparent motions. Nothing was known of the surface of the Moon, although it lies so close to us. Without the telescope mankind would have remained in comparative ignorance of the outer Universe. Is it wonderful, then, that John Kepler addressed the newly-invented instrument in these words: "O! telescope, instrument of much knowledge, more precious than any sceptre. Is not he who holds thee in his hand made king and lord of the works of God?"

Telescopes are of two kinds—the refracting telescope, the most familiar, and the reflecting telescope. Of these the refractor was the first to be invented. The first telescope was constructed in 1609 at Middelburg, in Holland, by an optician named Lippershey. The news of the construction of the first telescope reached Italy in the summer of 1609, when the idea of constructing one presented itself to the fertile mind of Galileo. In a letter, dated August 1609, Galileo wrote: "About two months ago a report was spread here—in Padua—that in Flanders a spy-glass had been presented to Prince Maurice, so ingeniously con-

structed that it made most distant objects appear quite near, so that a man could be seen quite plainly at a distance of two miles. This result seemed to me so extraordinary that it set me thinking, and as it appeared to me that it depended upon the laws of perspective, I reflected on the manner of constructing it, and was at length so entirely successful that I made a spy-glass which far surpasses the report of the Flanders one. The effect of my instrument is such that it makes an object fifty miles off appear as large as if it were only five."

Such were the humble beginnings of the telescope, the instrument which has revolutionised the science of astronomy. Galileo constructed a number of telescopes. The first was of little scientific value. The second was more useful, and with the third he commenced his observations on the Moon. With his fifth instrument he discovered the satellites of Jupiter.

The principle of the Galilean telescope is very simple. It is the simplest form of refractor through which the observer looks directly at the object of observation. The object-glass, or large glass at the end, was, in the Galilean telescope, a simple convex lens. After Galileo's time larger telescopes were constructed, but they were practically worthless, owing to a difficulty of construction which for a time seemed insurmountable. Owing to the dispersion of light (the principles of which cannot be explained in a work like the present) the image of the object was not well shown, the edges having fringes round them similar to the colours of the rainbow. This phenomenon, known as chromatic aberration, increased as the object-glasses increased in size. For some time, indeed, astronomers endeavoured to surmount the difficulty by making telescopes immensely long. Huyghens, Bianchini, and Cassini, astro-

nomers of the seventeenth century, constructed telescopes over a hundred feet in length. They were very unwieldy, and little scientific work of importance was accomplished by means of them. Thus, no effective antidote had been found for the chromatic aberration. Accordingly, Sir Isaac Newton, who devoted much attention to the subject, came to the conclusion that it was impossible to construct a refracting telescope which would be free from this defect. The same view was reached about the same time by the Scottish astronomer, James Gregory. Both Newton and Gregory agreed in condemning the refractor, and both commenced to devise a new form of telescope.

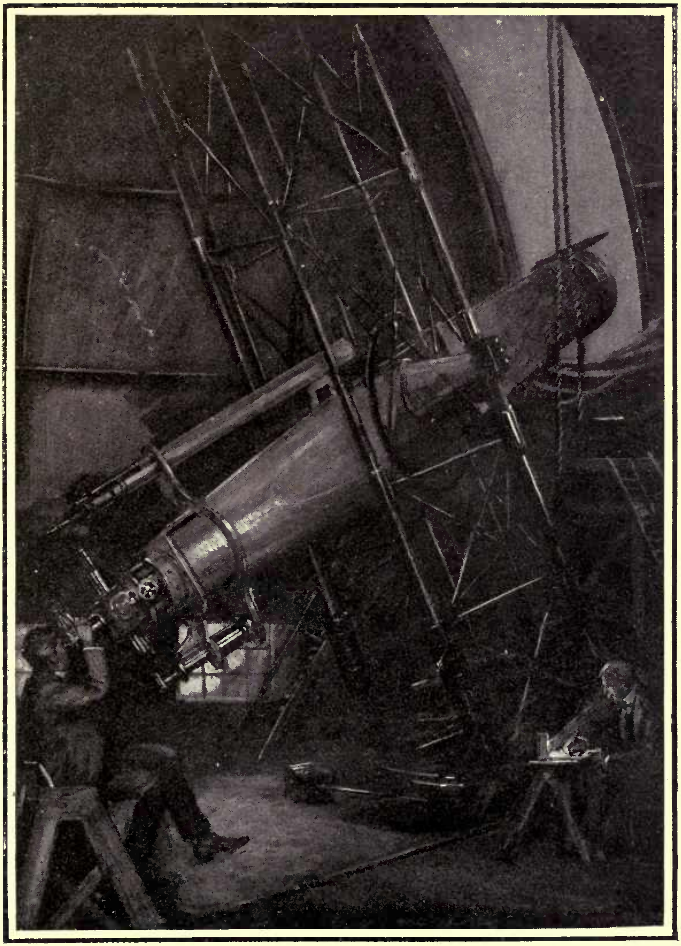
The form of telescope devised by them was the reflector, an instrument formed on the principle of the reflection of light. In this form of telescope the light coming into the telescope from the object to be observed was reflected into the eyepiece from the surface of a concave mirror constructed of the alloy known as speculum metal. Gregory and Newton constructed instruments which, while similar in principle, differed slightly in detail. One of the drawbacks of the reflector is that a second reflection is necessary before the rays from the object under observation can enter the eyepiece. If the observer looked down the tube of the telescope at the image, he would at once cut off the light from the object he wished to observe. Newton therefore in his telescope placed the eyepiece in the side, and into it the rays were deflected by a second reflection. Gregory, on the other hand, put the eyepiece immediately behind the principal mirror. The Newtonian form is the one most used.

After Newton's invention, the reflecting telescope became very popular. Its chief development was due to Sir William Herschel, who gave it immense popularity. It is a remark-

able illustration of the sequence of events that Herschel's development of the reflecting telescope was due to the fact that he was at first an amateur astronomer, who was obliged to make his own telescope. He constructed many reflectors and devised a modification of the Newtonian form, known as the Herschelian. In 1775, Herschel constructed his seven-foot telescope, and, after making instruments of ten, twenty, and thirty feet in focal length, he constructed in 1789 the famous forty-foot reflector with which he discovered the inner satellites of Saturn.

In the hands of Herschel, the reflecting telescope seemed to exhaust its possibilities, and men began to turn their attention to the despised refractor. In the eighteenth century it was found to be possible by combining lenses of flint and crown glass in the object-glasses of refractors to practically eliminate the "aberration" which had put a check on the advance of the refracting telescope. For some time it was found difficult to procure object-glasses of flint glass of sufficient size to make any considerable advance in telescope-construction. However, in the hands of a firm of Swiss opticians remarkable progress was made, and in 1823 a lens of 12 inches diameter was successfully finished.

Meanwhile, the greatest development of the reflecting telescope was soon reached. Most people have heard of Lord Rosse's telescope. It is, in point of size, about the largest telescope in the world, although its situation in the unfavourable climate of Ireland has rendered it practically useless within recent years. The history of this telescope is so interesting that it is worth giving at some length. When quite a young man, the third Earl of Rosse conceived the idea of erecting the largest telescope in the world on his estate in Ireland. Being an amateur, he turned his attention to the reflecting telescope. As the



At Work in Greenwich Observatory

This plate shows astronomers at Greenwich observing the planet Mars at its appearance in 1909. The room is quite dark except for the light which comes in from the night sky and the electric lamp by means of which one of the observers takes down his notes.

late Miss Clerke points out: "He had to rely entirely on his own invention and to earn his own experience. He had no skilled workmen to assist him. His implements, both animate and inanimate, had to be formed by himself. Peasants taken from the plough were educated by him into efficient mechanics and engineers." In 1827 he began work, and it was not until April 1842, fifteen years later, that he succeeded in constructing the famous mirror, six feet in diameter, with which he was to survey the heavens. By February 1845 the telescope was ready for work.

A tube, which resembled when erect one of the ancient round towers of Ireland, served as the habitation of the great mirror. The tube was no less than fifty-eight feet long and seven feet in diameter, so that when it was horizontal a man of considerable height could walk through it holding an umbrella. Sir Robert Ball, who for some years had charge of the great telescope, has the following interesting description of the instrument:—

"Almost the first point which would strike the visitor to Lord Rosse's telescope is that the instrument at which he is looking is not only enormously greater than anything of the kind that he has ever seen before, but also that it is something of a totally different nature. In an ordinary telescope he is accustomed to find a tube with lenses of glass at either end, while the large telescopes that we see in our Observatories are also in general constructed on the same principle. At one end there is the object-glass, and at the other end the eyepiece, and of course it is obvious that with an instrument of this construction it is to the lower end of the tube that the eye of the observer must be placed when the telescope is pointed to the skies. But in Lord Rosse's telescope you would look in vain for these glasses, and it is not at the lower end of the instrument that you are to take your station when you are going to make your observations. The astronomer at Parsonstown has rather to avail himself of the ingenious system of staircases and galleries by which he is enabled to obtain access to the mouth of the great tube."

Many valuable observations and discoveries were made by means of the Rosse telescope during the first few years of its existence, but it was not long before its powers began to deteriorate. Its situation in the unfavourable climate of Ireland greatly injured its usefulness, and it is now little more than an astronomical curiosity. It had only a few brilliant years of investigation and discovery. About the time the Rosse telescope was erected, a new material for the construction of reflecting telescopes was invented by two independent French investigators—glass upon which a thin film of silver is deposited. These instruments have a light-gathering power far exceeding the telescopes whose mirrors are constructed of speculum metal.

In June 1847 there was erected the famous Harvard refracting telescope of 15 inches aperture. This was the beginning of the development of the refractor. A 23-inch telescope on the same lines was constructed by a self-taught English optician in 1868; while a year or two later another self-taught optician, in America, followed with the construction of the famous 26-inch telescope of the Washington Observatory, rendered famous by the discovery by the late Professor Hall, when using it, of the satellites of Mars. Next in the eighties came the erection of telescopes of 29½ inches and 30 inches aperture respectively for the Observatories of Nice in France, and Pulkowa in Russia. The 30-inch telescope of the Russian National Observatory was for some years the greatest refracting telescope in the world. But it did not retain this position for long. As one writer puts it: "The Czar of all the Russias was outbidden twice by American millionaires."

The first of these was James Lick, whose name is now immortalised in connection with the great Observatory in California, where so many great discoveries have been

made. The story goes that Mr. Lick, a Californian millionaire, being very desirous of erecting a permanent memorial of himself and his wife, proposed to leave money for the erection of two immense statues on the Pacific coast. About this time, however, an astronomer suggested that, in case of war, such statues would be liable to destruction by the enemy, and that a great telescope erected on one of the mountains in California would be much safer. Accordingly Lick took up with much enthusiasm the erection of a gigantic telescope, making it a condition, however, that his remains were to be interred below the base of the instrument. He died many years before the Observatory was completed.

The late Professor Newcomb remarks that the erection of an Observatory was not in the millionaire's mind; all he wanted was a gigantic telescope. "From his point of view, as, indeed, from that of the public very generally, the question of telescopic vision is merely one of magnifying power."

An Observatory was, however, necessary in order to afford a house for the great telescope; but the idea of having the most powerful refracting telescope in the world was kept in view, and at last an object glass 36 inches in diameter was constructed. The Observatory was placed on Mount Hamilton, a lonely elevation 4250 feet in height, in California, amid the purest air, where a large instrument could be used to advantage. In 1888 the Observatory was finished, and the great Lick telescope entered on a long career of usefulness. Unlike the magnificent telescope of Lord Rosse, ruined by its situation in a poor climate, the great Lick telescope is still in the prime of its life. The discovery of new double stars, of a new satellite of Jupiter, the measurements of nebular

motion, within a few years of the erection of the telescope, is a testimony not only to the excellence of the instruments but the skill of the observers—men such as Professors Burnham, Barnard, Keeler, and Campbell, whose names are deservedly famous in astronomy. The colony of astronomers on Mount Hamilton is isolated from the rest of the world, and it requires a considerable amount of self-sacrifice to pursue astronomy under such conditions. "To those in actual charge of the telescope," says a well-known astronomer, "the situation is not without its disadvantages. They are at some distance from the town, and without many of the comforts of civilisation. The winter on the mountain is severe, and brings with it at times considerable privations. In one winter there was actually no water to drink except what had passed through the engines."

The great Lick telescope enjoyed for about ten years the place of the greatest telescope in the world. At length Mr. Yerkes, another millionaire, gave to the University of Chicago money to equip an Observatory and erect a telescope 40 inches in aperture, four inches greater than the Lick telescope. This great telescope was set up in 1898 at the new Observatory of the University of Chicago, Williams Bay, Wisconsin, eighty miles from Chicago. Here it is in the hands of expert observers.

Foremost among other astronomical institutions in America must be placed the Carnegie Observatory, on Mount Wilson, California. Dr. Andrew Carnegie, unlike Messrs. Lick and Yerkes, is deeply interested in all things scientific, and his munificent donations to the Carnegie Institute have conferred inestimable benefits on astronomy and astronomers. In 1905 the Carnegie Observatory on Mount Wilson was founded, and at its head

was placed Professor Hale, one of the most distinguished astronomers of the United States. Among the instruments erected here are the 60-inch reflector, with which much important work has been done, while greater things are expected from the 100-inch silver-on-glass reflector, which surpasses Lord Rosse's famous telescope in point of size. Like the Lick Observatory, the Carnegie Observatory is isolated from civilisation, and it is a matter of self-sacrifice to be an astronomer on Mount Wilson.

The view that a clear atmosphere is essential to good astronomical work has been maintained for many years by Professor Percival Lowell, who established in 1894 the now famous Lowell Observatory at Flagstaff, Arizona. Here he erected his 18-inch and 24-inch refractors, which he claims to be almost unrivalled for space-penetrating power, and here also he proposes to erect a 40-inch reflector for photographic purposes. Work amid surroundings so far removed from human habitation entails, as we remarked, a good deal of self-sacrifice, but, as indicated by Professor Lowell's remarks, it seems to have also a certain charm: "To sally forth into the untrod wilderness in the cold and dark of a winter's small hours of the morning, with the snow feet deep upon the ground and the frosty stars for mute companionship, is almost to forget one's self a man for the solemn awe of one's surroundings. Fitting portal to communion with another world, it is through such avenue one enters on his quest, where the common and familiar no longer jostle the unknown and strange."

The Harvard College Observatory in Massachusetts has none of the advantages of the great institutions already named, so far as climate is concerned; yet it has a reputation and a record second to none. Professor

E. C. Pickering, director of the Observatory, has raised the institution to a high standard of efficiency. Photographic work is one of the specialities of the Observatory. He charts the sky once a month ; with a smaller instrument, and on a smaller scale, he charts the brighter stars every fine night, so that if a star brighter than the sixth magnitude makes its appearance in any part of the heavens, he would have a record of it on the first clear evening.

Turning from the great institutions of the New World to the more historically interesting Observatories of the Old, we find two—Greenwich Observatory and Paris Observatory—which have the greatest historical interest in the world. The Paris Observatory was erected a few years before the sister institution, being completed in 1671. Four years later was laid the foundation-stone of the Royal Observatory at Greenwich, of which the famous John Flamsteed was made director, with the title of Astronomer Royal. It is not too much to say that the science of practical astronomy was founded at Greenwich. The work of Bradley, the third Astronomer Royal, forms an epoch in the history of astronomy. The history of this great and honourable institution would take too long to record here. The object for which the Observatory was founded—practical astronomy—is still regarded as the chief side of the work, and for this a large instrument is not required. Still Greenwich is at the same time thoroughly progressive, and a good deal of photographic and observational work is done. The Observatory boasts a 28-inch refractor, a very fine instrument.

The Paris Observatory is also deservedly famous, having been presided over by a succession of famous men, who have done much for the development of astronomy. These two Observatories occupy the chief places among the institutions in Europe for the cultivation of astronomy.

Other famous Observatories in Europe include Edinburgh, Potsdam, Pulkowa, Heidelberg, Milan, and Rome.

The Edinburgh Observatory was founded in 1776—a century after the Greenwich Observatory—and was originally the property of the Astronomical Institution of Edinburgh, being erected for the convenience of members of the institution who wished to make practical observations. It was enlarged in 1811, and with its instruments the famous astronomer Henderson, who first measured the distances of the stars, made his earliest observations. In 1834 the Observatory, which occupied a fine position on the Calton Hill, Edinburgh, became Government property. It was converted into a Royal Observatory, and at its head was placed Thomas Henderson, Professor of Astronomy in the University of Edinburgh, who became Astronomer Royal of Scotland. In 1896 a new Royal Observatory was erected on Blackford Hill, in the outskirts of the city, away from the smoke of the city. The new institution is second only to Greenwich among British Observatories. The old Observatory buildings on the Calton Hill were acquired by Edinburgh Town Council. The Council converted them into a City Observatory, mainly for educational purposes. It, however, possesses the largest telescope in Scotland, a 22-inch refractor.

The Observatory at Potsdam is equipped with a magnificent 28-inch refractor. This institution is known as an "Astrophysical Observatory," because the new side of astronomy—the study of astrophysics, the physical investigation of the heavenly bodies—is chiefly pursued there. The Observatory was founded in 1874, and was the scene of the labours of the great German astronomer Vogel.

Pulkowa Observatory was founded in 1835 by the Czar of Russia. It was equipped with what was then one of the

greatest telescopes in the world, while one of the most famous astronomers, William Struve, the German observer, was placed at its head. In 1884, under his son and successor, Otto Struve, the Observatory was furnished with what was at that time the greatest telescope in the world. It is now, however, much behind the American Observatories in point of the size of its telescopes. It has been directed by a succession of very able astronomers.

The Heidelberg Observatory is of no great antiquity, but its record is a noble one. It was erected in 1893, and at its head was placed Professor Max Wolf, the great astronomical photographer. Here was erected the famous photographic telescope by means of which Dr. Wolf has secured his beautiful photographs.

The Italian Observatories of Milan and Rome are famous chiefly from the historical interest which attaches to them. The Brera Observatory in Milan was the scene of the work of Professor Schiaparelli for upwards of forty years. Favoured with a magnificent sky and a fair-sized instrument, Schiaparelli certainly made the most of his opportunities. The Observatory of Rome was the scene of the labours of the two distinguished men Secchi and Tacchini, who, favoured by the beautiful climate of Italy, were also enabled to make the most of their opportunities in a different field of astronomical research—solar and stellar physics.

Among the Observatories in the southern hemisphere three may be mentioned specially—the Cape Observatory, the scene of the work of Thomas Henderson and more recently of Sir David Gill; the Cordova Observatory in Argentina; and the Observatory at Arequipa in Peru. The last named is the southern observing station of Harvard College Observatory, which thus surveys both hemispheres of the sky.

CHAPTER XXIX

THE ROMANCE OF DISCOVERY: THE EARLY ASTRONOMERS

IN the previous chapters, reference has been made to the vast amount of knowledge which has been amassed by the human race concerning the Universe and the place of our world in Nature. In the early ages of our world's history, mankind was sunk in ignorance regarding the heavenly bodies, as was clearly shown in the opening chapter. To-day we have acquired a considerable insight into the system of the Universe at the present time, and have even dared to attempt to read the past of the Universe and to trace its future. The advance of astronomy throughout the ages has been like that of a mighty army marching to victory. The march has been a triumphal progress so far, but we are no nearer the end, for as soon as one stage of the journey is reached, new and unfathomable vistas come into view.

Carlyle has remarked that the history of the world is the history of its great men; and it is equally true to say that the history of astronomy is the life-story of astronomers. Of these the earliest are lost in the mists of antiquity, and the name of the first astronomer will probably remain for ever unknown. In the early ages, students of the heavens were not merely astronomers. Thus, Aristotle, who exercised so profound an influence on astronomy, was an all-round scientist and philosopher. The first astronomer, in the actual sense of the word, was

Hipparchus. He was born about 170 B.C. He constructed a catalogue of the positions of the stars, an idea supposed to have been suggested by the appearance of a temporary star. Hipparchus died about 120 B.C. Over two hundred years later, Ptolemy described him as a "most truth-loving and labour-loving man."

One of the most famous of the ancient astronomers was the Egyptian, Claudius Ptolemy, who is supposed to have lived at Alexandria between about A.D. 127 and 157. Ptolemy's ideas of the Universe were believed for fourteen hundred years, and he propounded the famous "Ptolemaic theory," which was eventually upset by Copernicus. Ptolemy considered, like Aristotle, that the Earth was round and immovable. The celestial bodies were thought to revolve round it in the following order: the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the stars proper. The planets were believed to revolve in circles round imaginary centres, which revolved in circles round the Earth. This theory was preserved in Ptolemy's great work, "The Almagest."

After the death of Ptolemy the science of astronomy was taken up by the Arabians, the chief of these being Ulugh Beg, King of Samarcand, who lived in the fifteenth century. He made a catalogue of the stars more perfect than that of Hipparchus, and it remained the finest until the days of Tycho Brahe. Ulugh Beg was assassinated by his son, who desired the throne, in 1447, twenty-six years before Copernicus was born. It had become plain even before the time of Ulugh Beg that the theory of Ptolemy was very complicated. Eventually, Alphonso X., King of Castile, who took a great interest in astronomy, on hearing explained to him the Ptolemaic theory, declared that if he had been consulted

at the Creation he could have given some useful hints. This is often considered to have been an irreligious remark, but we must remember that Alphonso X. was dissatisfied with Ptolemy's views. The ancient astronomers ended with Ulugh Beg. Though Pythagoras had said that the Earth moved, the end of the fifteenth century found the world more ignorant of astronomy than it had been in the time of Aristotle and Hipparchus. Astronomy was therefore prepared for the revolution of Copernicus.

The system of astronomy according to Aristotle and Ptolemy was implicitly accepted during the Middle Ages. The Church of Rome contrived to make the Ptolemaic system agree with its own particular interpretation of the Bible, and thus it was that nobody thought of questioning whether Aristotle was right or wrong until Copernicus came upon the scene. As has been well said: "All who in these days value freedom of thought, every man who now follows freely and honestly the leading of the mind and conscience God has given him, owes no small debt to the old monk who, in the solitude of the monastery garden at Frauenburg, thought out the overthrow of the authority of Aristotle."

Nicolaus Copernicus, the founder of modern astronomy, was born at Thorn, on the Vistula, in Poland, in 1473. He was the son of a tradesman named Nicolaus Copernicus, and his uncle was a bishop in the Cathedral of Frauenburg. It has been pointed out as a remarkable coincidence that the great astronomer had just reached manhood when Columbus discovered America. Copernicus was educated at the University of Cracow, where he devoted himself first to medicine and philosophy, and afterwards to astronomy, mathematics, and painting.

After spending some years in various parts of Italy, Copernicus, in 1500, went to Rome, and was appointed Professor of Mathematics. Here he studied astronomy in earnest, and was universally acknowledged to be a great man of science. He did not remain long in Rome, but returned to Poland, where he settled at the Cathedral of Frauenburg as a priest, devoting himself to astronomy and to his duties as an ecclesiastic. He was of a grave and serious nature, and made only a few intimate friendships.

Early in his career Copernicus came to doubt the truth of the Ptolemaic theory on account of its complications. He noticed that everything was done in Nature by the simplest methods. Every new irregularity which was discovered in the motions of the planets required a new epicycle, making the system of Ptolemy so complicated that it could scarcely be understood. Another great difficulty which Copernicus noticed was that the stars were represented as revolving round the Earth in the short space of twenty-four hours. Some suggestions that had been made by the ancient Greeks specially struck him. Nicetas had suggested the rotation of the Earth on its axis to account for the diurnal motion of the heavens, a suggestion which Ptolemy considered and rejected. Philolaus thought that the Earth moved, and not the Sun. These considerations led Copernicus to revolutionise men's ideas of the entire planetary system.

The first great discovery of Copernicus was that of the rotation of the Earth on its axis. An argument which Ptolemy had used in trying to prove that the Earth did not rotate, namely, that there would be such a rush in the atmosphere as would carry men off the surface, Copernicus answered by showing that the inhabitants would be carried

by the Earth in the same manner as a man carries his overcoat. Copernicus also showed that it was much simpler for the Earth, along with the other planets, to revolve round the Sun, in an orbit between those of Venus and Mars, than for the Sun and planets to revolve round the Earth. He also said that, if his opinions were correct, Venus and Mercury should exhibit phases like the Moon. In the case of Venus these phases were discovered telescopically by Galileo in 1611, and Mercury was also proved afterwards to show phases. In the case of the stars Copernicus made little advance. The absence of parallax on account of the Earth's motion was for long considered a great drawback to the Copernican theory. Copernicus declared that the distance of the stars must be so enormous that there would be little or no parallax.

Copernicus did not at once publish his great discoveries. Still his opinions were well known. Men of science flocked to Frauenburg out of curiosity to know of the new system, and went away convinced that it was true. Copernicus' friends had repeatedly urged him to have his works published in book form, but he refused. An event happened, however, which caused him to give his system to the world. A young admirer, George Joachim, or Rheticus, gave up his position as Professor of Mathematics in the University of Wittenberg in Germany in order to go to Frauenburg to hear the opinions of Copernicus. He soon became convinced of the truth of the Copernican system. In 1541, when Copernicus was an old man of sixty-eight, he agreed to give his book to the world, and gave over the care of the publication to Rheticus, who had the book printed at Nuremberg in Germany, by a man named Andrew Osiander. The great work, which was entitled "De Revolutionibus Orbium Cœlestium" was published in 1543. Osiander

who published it was afraid of the opposition which it would arouse, and wrote a preface to the book saying that the opinions of Copernicus were merely founded on theory, and need not be received as true. Copernicus died suddenly at the age of seventy, on May 23, 1543. A few hours before his death he received the first copy of his great work. He was buried in the Cathedral of Frauenburg, and no mention of his great discoveries was made on his tombstone. Not until thirty years after his death was any memorial erected to his memory. When he died, astronomy was left in a most unsettled state. The tables of the planetary motions predicting eclipses, conjunctions, oppositions, being based on the observations of the Greeks and the Arabs, were often several hours or days wrong. It was thus obvious that until the motions of the planets had been more correctly investigated, the question of the true system of the world must remain more or less unsolved.

Three years after the death of Copernicus, in 1546, there was born at Knudstrup, in Denmark, one who was destined to place astronomy on an entirely new basis—that of exact observation. His name was Tycho Brahe. He was the eldest son of a Danish nobleman, Otto Brahe, and was educated by his uncle, George Brahe. When he was thirteen years of age he was sent to the University of Copenhagen, and an eclipse of the Sun which happened in 1560 directed his thoughts to astronomy. His uncle, however, desired him to study law, and, to take his attention from science, sent Tycho to the University of Leipzig, in Germany. Dr. Dreyer, to whom all interested in astronomy are indebted for his admirable biography of the great Danish astronomer, informs us that Tycho was accompanied to Leipzig by a young man named Vedel, who acted as his tutor. George Brahe had instructed Vedel

not to allow Tycho to continue studying astronomy, which in those days was looked upon as a waste of time, and a most undignified occupation for the son of a nobleman. But Tycho was not to be diverted from science, having no interest whatever in the study of law. He bought, unknown to his tutor, a small celestial globe in order to know how to find the stars. He could only use it while Vedel was asleep. Tycho's first instruments were a pair of compasses, one leg of which he could point at the object observed, and the other at some known fixed star, and so could measure their angular distance apart. By this time Vedel had found that Tycho had no interest in law. Tycho's uncle died in 1565, and he was free to study the stars. His relatives, who considered it a disgrace to study astronomy, began to despise him, but nothing would now distract him from his favourite study.

Being looked upon with contempt by his relations, Tycho in 1566 left Denmark for Germany, settling at Wittenberg in April and at Rostock in September. At Rostock two events took place of great interest. In the earlier part of his life Tycho was a firm believer in astrology, and he declared that the eclipse of 1566 foretold the death of the Sultan of Turkey. Some time later the news arrived that the Sultan was dead, but that he had died before the eclipse. It is satisfactory to know that Tycho gave up his belief in astrology at a later period of his career. He had a violent temper, and in the end of 1566 quarrelled with another Dane living at Rostock as to which was the better mathematician, the result being that a duel was fought in which Tycho was seriously wounded.

Tycho Brahe had come to the conclusion that the true arrangement of the planetary system could not be ascertained until the planets and stars had been carefully observed and

their positions noted, instead of relying on the primitive and imperfect observations of the Greeks and Arabs. After leaving Rostock he went to Augsburg and erected in that town for the brother of the Burgomaster a large quadrant for noting the positions of the stars. In those days the telescope was unknown, and quadrants and sextants were the principal instruments of astronomers. In 1570 Tycho left Augsburg for Denmark. About this time Tycho's time seems to have been occupied with chemistry, and one of his uncles permitted him to use an outhouse as a laboratory. Tycho pursued the study of chemistry until 1572, when a great astronomical event finally directed his attention to the stars.

On November 11, 1572, when Tycho was returning from his laboratory, he observed a brilliant new star in the constellation Cassiopeia. At first it rivalled Venus in brilliancy, and Tycho's observations showed that it had no parallax, and was therefore among the stars and did not belong to the planetary system. The light of the star now rapidly faded, but Tycho made many important observations on it. He published a book on the star named "De Nova Stella," in which he gave a detailed description of all the observations which he had made. The publication of this work greatly annoyed Tycho Brahe's proud relations, who considered it undignified for a nobleman to write a book. In 1574 Tycho lectured on the stars in Copenhagen, but he had already made up his mind to leave Denmark and settle in Germany. King Frederick II. of Denmark saw that honour would be conferred upon his country if he could persuade Tycho to remain in Denmark. In 1576, therefore, the King granted to Tycho a pension and the use of the island of Hven, near Copenhagen, on which he might build an Observatory to carry on his studies.

Tycho accepted the offer, and the Observatory was entirely completed by 1580. It was called "Uraniaborg," or "The City of the Heavens," and it was there that Tycho accomplished that work which has given him a place among the greatest astronomers who ever lived. He made observations on the planets of the utmost importance, and he formed a star catalogue. When Tycho went to observe the stars he put on robes of state, as it was his belief that he could not show enough reverence when entering the presence of the great orbs of heaven.

In 1577 Tycho dealt a severe blow at the authority of Aristotle by upsetting the ancient views of comets. Aristotle had declared that comets were atmospheric and much nearer than the Moon, but Tycho showed that they were situated among the planets. In 1588 he published a book on the comet of 1577, and in this he gave to the world the "Tychonic System." Tycho Brahe was opposed to the view of Copernicus, though he had a high opinion of that great astronomer. He likewise opposed the Ptolemaic system, and was led to found the Tychonic system, a combination of the Ptolemaic and Copernican theories, in which the planets were believed to revolve round the Sun, which along with the Moon and stars revolved round the Earth. This error was, however, of little importance, as it was in observational astronomy that the great work of Tycho was accomplished.

Tycho remained at Hven for twenty years. In 1588 King Frederick died and was succeeded by his son, King Christian IV., then only eleven years of age. In 1597 he took the power into his own hands, and several serious charges were brought against Tycho. He had been given a cathedral, which he had allowed to fall into disrepair. He had quarrelled with one of the people of Hven, and the

high noblemen were jealous of his pension. Tycho had a quick temper, but this does not at all justify King Christian in stopping Tycho's pension, and forbidding him to carry on his observations at Copenhagen. In June 1597 Tycho and his family left Denmark for ever and settled in Germany. The great astronomer moved restlessly from place to place. He wrote from Rostock a humble and kindly letter to the King, asking him to restore his pension. But Christian refused, and after two years of wandering over Germany, Tycho settled at Prague, in Bohemia, in 1599. He was honoured by the Emperor Rudolph of Bohemia by his appointment as Imperial Mathematician, and in 1600 Kepler became his assistant.

But though only fifty-four years old the anxiety, and exile from Denmark, proved too much for Tycho, and after a short illness he died at Prague on October 24, 1601. For some time before his death he was heard to exclaim, "Ne frustra vixisse videar!"—"Oh that I may not be found to have lived in vain!" He asked Kepler to use the observations made by him and to publish them as the "Rudolphine Tables." Tycho was buried in Prague, where a great statue was erected to his memory. Had it not been for Tycho, the truth of the Copernican theory, which he opposed, would not have been proved for many years after. To Tycho Brahe we owe the foundation of accurate observation which has made astronomy the most exact, the most wonderful of all the sciences.

CHAPTER XXX

THE ROMANCE OF DISCOVERY: GALILEO AND KEPLER

WHILE Tycho Brahe had rejected the Copernican system in favour of an idea of his own, there were living two men who spread the new theory in Italy and Germany. These men were Giordano Bruno and Michael Mästlin. Bruno spread the new theory in Italy, and also in England, in a more daring manner than Mästlin did in Germany, and for refusing to abjure his belief he was burned alive as a heretic at Rome in 1600. Mästlin was the tutor of Kepler, and informed him of the truth of the system of Copernicus. As yet, however, nobody had proved the truth of the theory, and when it had been rejected by such a great man as Tycho Brahe, it seemed as if it must still remain a theory. It was here that there came into fame the great Italian astronomer, who proved that the Copernican theory was true, and who suffered the most cruel persecution at the hands of the Church of Rome.

Galileo de' Galilei was born at Pisa in 1564. He was the eldest son of Vincenzo de Bonajuti de' Galilei, an Italian nobleman residing at Pisa. At first his father intended him to be a cloth merchant. He was sent to a school in Vallombrosa, and made such progress in his studies that his father decided that he should adopt the profession of medicine. When he was seventeen years

of age Galileo entered the University of Pisa. In a short time he learned mathematics, which he studied with great perseverance, much to the displeasure of his father.

Galileo had not been long at the University when he perceived that Aristotle was by no means an infallible guide in scientific affairs, and he was not afraid to ridicule the Aristotelian authority, much to the annoyance of the professors at Pisa. He also devoted himself to painting and music, and for some time intended to become an artist. When he was twenty-one years of age Galileo left the University, and four years later he was appointed Professor of Mathematics at Pisa. Here he made his first great attack on the Aristotelians. Aristotle had declared that if two bodies were dropped to the ground from the same height, the heavier would reach the ground before the lighter. Galileo said that both would reach the ground simultaneously. To prove that he was correct, Galileo, in presence of a large number of people, dropped two bodies of unequal weight from the top of the Leaning Tower of Pisa. Both reached the ground at the same time. This was a triumph for Galileo, but instead of admitting that they had been wrong, the Aristotelians made his professorship at Pisa so unpleasant that he resigned. In 1592 he was appointed Professor of Mathematics at Padua. Here he lectured on scientific subjects with great popular success. In 1602 he invented the thermometer.

In a letter to Kepler in 1597, Galileo remarked that he had adopted the Copernican system many years before. At first he had laughed at the new idea, but he found that, while many of the followers of Ptolemy had become Copernicans, no follower of Copernicus ever adopted the old system. Galileo, however, was forced to teach the

Ptolemaic system at the University, keeping his views to himself.

But the greatest of Galileo's discoveries had yet to come. Hearing that Lippershey, a Dutch optician of Middelburg, had made an instrument by which "a man at a distance of two miles could be clearly seen," Galileo at once set about constructing an "optic tube," as the telescope was then called, and when he had made one there was quite a rush to see it. In 1609 he presented a little tube to the Senate at Venice. He then made another and more powerful telescope, the style of which is now known as the Galilean refractor. He was amazed to find that he could see ten times as many stars through the telescope as he could see with the naked eye. He examined the Pleiades, Orion, the cluster Præsepe, and other star clusters. The Milky Way was now resolved into stars.

In January 1610 Galileo directed his telescope to Jupiter. He noted three stars near the planet. Next night, to his amazement, he found that the three stars had moved as well as Jupiter. Some nights later a fourth was discovered, and Galileo concluded from their changing positions that they revolved round Jupiter as the Moon revolves round the Earth, and the planets round the Sun. This confirmed the truth of the Copernican theory. Several people, as already mentioned in a previous chapter, refused to look into the telescope in case they might see the satellites and be convinced.

Galileo discovered some time later that Venus exhibits phases similar to the Moon. Copernicus had said that Venus would show phases if his theory was correct. Once again Galileo confirmed the truth of the Copernican system. He also examined the Moon, and discovered that its surface was covered with mountains and craters; he

found that the Sun had black spots on its surface; that Mars showed phases, greatly to the disgust of the Aristotelians. Galileo next discovered that the planet Saturn was elliptical in shape, but he could not explain the cause. It was not explained until Huyghens took up the subject in 1656.

Galileo left Padua in 1610, and went to Florence with the title of Mathematician and Philosopher to the Grand Duke of Tuscany. In leaving Padua he made a great blunder in transferring himself from the free Republic of Venice to Tuscany, where the Church of Rome was all-powerful. At length Galileo's ideas about the Universe, now widely known, were pronounced to be opposed to the Bible. In 1615 he went to Rome and continued to teach the Copernican theory. For this he was summoned before the Inquisition, and the Copernican system was condemned. Pope Paul V. warned Galileo not to teach the new system as if it were true.

After Paul V. was dead, in 1623 Cardinal Barberini was elected Pope as Urban VIII. The Pope had been, while still a cardinal, a great friend and admirer of Galileo, and the astronomer therefore considered that he was now at liberty to teach the Copernican theory. He prepared to write his work, "The Dialogue of the Two Principal Systems of the World, the Ptolemaic and the Copernican." It was written in the form of conversations between three men. Galileo was very careful, and by writing it in the form of conversation, which did not indicate the views of the author, he obtained permission from the Pope and the Inquisition to have his work published. The book was given to the world in June 1632. Presently, however, the Church of Rome regretted having allowed the publication. One of the characters in the dialogue was named "Simplicius," and it was he who upheld the Ptolemaic

system. Some ignorant priests represented to the Pope that "Simplicius" was meant to represent himself and hold him up to ridicule. Orders were then given for the seizure of every copy of the book, which was condemned as heretical.

The Pope ordered Galileo to appear before the Inquisition at Rome. Being sixty-nine years of age, he begged to be excused from the journey. But Urban, acting in much the same hard-hearted manner as the King of Denmark had acted towards Tycho Brahe, was enraged and said that the command must not be disobeyed. In February 1633 Galileo arrived in Rome, and four months later was tried before the Inquisition for teaching the Copernican system. On June 22 he was compelled to kneel before the cardinals of the Roman Church, and, with threats of death, was ordered to declare that he would in future "detest the false opinion that the Sun was the centre of the Universe and that the Earth moved." Rising from his knees, tradition says, he whispered to one standing near him—"E pur se muove!"—"For all this, it does move!"

Galileo was sentenced to be imprisoned as long as Pope Urban desired. His health, however, suffered from the intense heat at Rome, and he was allowed to return to his house at Arcetri, near Florence, in which he was commanded to remain in everlasting solitude. At last came the tragedy at the end of his life. His sight began to fail, and in the end of 1637 he became totally blind. On January 2, 1638, he wrote thus to a friend: "Alas, your dear friend and servant Galileo has been for the last month perfectly blind, so that this Heaven, this Earth, this Universe, which with wonderful observations I had enlarged a hundred, a thousand times beyond the belief of bygone ages, henceforth for me is shrunk into the narrow space which I myself fill in it. So it pleases God; it shall therefore please me

also." Galileo died at Arcetri on January 8, 1642, aged seventy-seven, having been blind for four years. Even after he was dead the Pope would not allow a monument to be erected to his memory. Still, despite the foolish attempt to crush the Copernican system, Galileo, though he died in misery, was in the end triumphant.

While Galileo was confirming the Copernican theory by observation, another great man was confirming it by mathematics. By means of difficult calculations he made discoveries as brilliant as Galileo made with the telescope, and his calculations, which were based on Tycho Brahe's observations at Uraniaborg, finally led to Newton's discovery of universal gravitation. The name of this man was Johann Kepler. He was born at Weil der Stadt, in the duchy of Würtemberg, in Germany, in 1571, and was thus the first of those great German astronomers to whom science has owed so much. Kepler was the son of a soldier, and his grandfather was the Burgomaster of Weil der Stadt. Kepler, who was always in very poor circumstances, was educated at the school at Maulbraun, which was preparatory to the University of Tübingen. At length, when he was seventeen years of age, he entered the University of Tübingen, and learned from Mästlin, the Professor of Mathematics there, that the Copernican theory was the true one. When Kepler left the University he was without means, and had no prospect of employment. Shortly afterwards, however, the Professorship of Astronomy at Grätz fell vacant through the death of the Professor, and Kepler, who as yet had no special inclination for astronomy, was offered it and urged by his friends to accept it, which he did with considerable reluctance. He was then twenty-three years of age.

It was while he was at Grätz that Kepler hit upon a theory which, though long since discarded, was very ingenious.

He considered that the "five regular solid figures" known to mathematicians corresponded with the five planets, Mercury, Venus, Mars, Jupiter, and Saturn. The idea was a daring one, but is now absolutely useless. All the same it made Kepler prominent in the world of science. He wrote a book advocating it, and by means of this book he became known to Tycho Brahe and Galileo. As the inhabitants of Grätz were chiefly Roman Catholics, all the Protestant Professors were expelled in 1599, Kepler among them. But he had now become a famous man of science, and he was restored to his position. However, he had no pupils, and he was glad in 1600 to accept the post of assistant to Tycho Brahe near Prague.

When Tycho Brahe was dying in 1601 he requested Kepler to use his observations, which had been collected at Uraniaborg from 1577 to 1597, believing that by means of these observations the true system of the Universe would at last be revealed. After Tycho's death Kepler was appointed to succeed him as "Imperial Mathematician" to the Emperor Rudolph. He was promised a handsome salary in his new post, but it was never paid. Tycho expressed the wish that the observations might be continued after his death, but this wish was not to be fulfilled. Kepler, faithful to the last wishes of the Danish astronomer, commenced to observe Mars with the great telescopes which Tycho had brought from Uraniaborg. In 1602, however, Tycho's son-in-law Tengnagel, who pretended to be interested in astronomy and was jealous of Kepler, deprived him of the instruments, and promised the Emperor Rudolph that the planetary tables would be finished within four years. Kepler never saw the instruments again, as they were stored away in an old vault, and they were probably destroyed in the Bohemian rebellion of 1619. As to the observations

of Tycho, Kepler at last got access to them, and Tengnagel soon abandoned the idea of working at the Rudolphine tables, which now occupied the attention of Kepler.

As has been already mentioned, Kepler's promised salary was never paid, and for years he was, as he himself remarked, "begging his bread from the Emperor." Owing to his poverty he was unable to publish the Rudolphine tables for about twenty years. Some time after the death of Tycho, Kepler published a book on comets. In 1609 he published "Commentaries on the Motions of Mars," the work which contained the first of the three laws of planetary motion, which showed that the planets revolved round the Sun in elliptical orbits. Kepler could not reconcile the observations of Tycho with the theory of circular orbits. There was not a very large difference, and many men would have accounted for the difference by the supposition that Tycho had made a mistake, and would thus have lost the chance of making a great discovery. But Kepler knew Tycho Brahe, and he was certain that the great astronomer could not have made so large an error. Kepler's second law was published in a few years after the first. The irregularities in the motions of the planets were now accounted for, and the great laws of Kepler removed the difficulties which stood in the way of the acceptance of the Copernican system, and confirmed it as conclusively as did the telescopic observations of Galileo. The observations of Tycho Brahe confirmed the system of Copernicus, which he himself had rejected.

Kepler was still in extremely poor circumstances, and accordingly he asked the Emperor to pay his salary. Rudolph ordered it to be paid, but the Bohemian exchequer was empty. In 1610, the year of Galileo's great telescopic discoveries, Kepler suffered almost every sorrow imaginable.

He was in great poverty; the Austrian troops occupied Prague, his wife died, and his favourite son also died. He went to Austria to secure a professorship at Linz, but Rudolph would not allow him to leave Prague, and promised to pay his salary, but again failed to keep his promise. At this time Kepler was in such extreme poverty that he was compelled to write what he called "a vile prophesying almanac," filled with astrology, in which he did not believe. It has been pointed out as remarkable that "the world would not give him bread for his astronomical discoveries, but it would give him money for what he knew to be lies." Rudolph died in 1612, and the new Emperor Mathias, his brother, allowed the astronomer to accept the professorship at Linz, and asked him to also retain the position at Prague.

During all his misfortunes Kepler exhibited a beautiful nature. In January 1610 the satellites of Jupiter were discovered by Galileo. Kepler was the only man who accepted the discovery without hesitation, even though it ran counter to his ideas of the "five regular solids." He welcomed the news of his friend's success. A follower of Kepler attacked Galileo, accusing him of having plagiarised some of the former's discoveries, for which Kepler compelled the man to apologise to the Italian astronomer. Another instance of his fine nature can be given. "One of his rejected theories," writes one of his biographers, "assumed a new planet between Mars and Jupiter. Kepler was afraid that this might be mistaken by a careless reader to be an anticipation of Galileo's discovery of the satellites of Jupiter; and so in a subsequent edition of his work ('The Five Regular Solids') published in 1621, he adds a note referring to his supposed planet: 'Not circulating round Jupiter like the Medicean[1] stars. Be not deceived. I never had them in my thoughts.'" Before leaving this subject, it may be noted

[1] Another name for the satellites of Jupiter.

that Kepler's prediction of a planet between Mars and Jupiter was, as we have seen, confirmed by the discovery of the early asteroids by Piazzi and Olbers a hundred years ago.

Kepler was soon expelled from Linz on account of his Protestantism. He refused in 1617 to accept a professorship at Bologna with a large salary. In 1619 he published his third law in a work entitled "The Harmonies of the World," dedicated to King James VI. of Scotland. The discovery of this law was the aim of his life. In 1622 he wrote the "Epitome of the Copernican Astronomy," defending the Copernican system. The book was at once prohibited by the Church of Rome. At last in 1621, the Rudolphine tables, the result of the labours of Tycho Brahe, were published, and in recognition of this work, and of his services to astronomy, Kepler received a gold chain from the Grand Duke of Tuscany. In 1620 a proposal was made to Kepler that he should leave Germany and go to England. But he declined to leave his native country.

When Kepler was fifty-seven years of age, he received an offer to live under the protection of the Duke of Freidland. A professorship at Rostock was also given to the great astronomer, and his future career seemed hopeful. Before leaving Bohemia, however, he made a journey to Ratisbon to procure the salary which had never been paid to him. But anxiety about the payment of his money proved too much for him. His health, always delicate, gave way, and while at Ratisbon he was seized with illness and died in 1630. He was buried in St. Peter's Church in Ratisbon, where a hundred years ago a great statue was erected to his memory.

The last of the great astronomers before Newton was Huyghens, the Dutch scientist. Huyghens was born at the Hague in 1629. He was the second son of the Dutch poet, Constantine Huyghens, counsellor to the Prince of Orange. When he was thirteen years of age, Huyghens began to take

much interest in mathematical studies, and examined every piece of machinery he could lay hold of. He was educated at the University of Leyden, and was, like Tycho Brahe, intended to study law, for which he was sent to Breda. But the bent of his mind was towards science, and when he was twenty-four years of age he wrote some treatises on geometry, studying that subject until 1651, when he devoted himself to observational astronomy.

Since the death of Galileo, the founder of telescopic observation, there had been little improvement in the making of telescopes, and no further discoveries had been made in the celestial regions. The mystery of Saturn, which puzzled Galileo, remained a mystery; nothing was known regarding nebulæ, while, with the exception of Galileo's discoveries of the Martian phases and a few observations by Fontana at Naples in 1636 and 1638, the study of the planet Mars had not yet been begun; in fact, until Huyghens arrived upon the scene, telescopic observation remained at a stand still. In 1655 Huyghens, with the help of his brother, set about telescope-making. By a new method he ground and polished lenses which were much more powerful and much more perfect then those used by Galileo. Huyghens then commenced to observe the planet Saturn in order to solve the mystery of its elliptical appearance. As mentioned in a previous chapter, the famous ring of Saturn was detected by Huyghens. He was also the first to study nebulæ. On June 16, 1659, he presented the first "pendulum clock" to the States-General of Holland, the invention being the result of accurate astronomical observations. Huyghens in 1660 visited England, where he solved some problems in mathematics. He left Holland in 1665, and settled in Paris at the invitation of Louis XIV. In France he devoted himself to other researches besides astronomy and mathematics. Like his illustrious con-

temporary Newton, he speculated in chemistry, and discovered the true nature of light, which perhaps forms the boundary line between astronomy and chemistry. He found that light travels through space in the form of waves, a view which did not command universal acceptance until about a hundred years ago, when it was revived and established.

Huyghens remained in Paris until 1681, when the persecution of the Protestants compelled him to return to Holland. Here he continued his astronomical observations. He constructed telescopes of enormous length known as "aerial telescopes," and three of his object-glasses are still in the possession of the Royal Society. He invented an almost perfect eyepiece, known as the "Huyghenian eyepiece," which is still extensively used. It is also interesting to know that Huyghens was one of the strongest supporters of the theory of life on other worlds. In his work, the "Cosmotheoros" (published at the Hague in 1698, shortly after his death), he speculated regarding the possible inhabitants of the planets, and brought forward arguments in favour of the plurality of worlds. Unfortunately Huyghens did not accept Newton's view that gravitation was universal, although he admitted that it regulated the movements of the planets. It was with considerable difficulty that he could accept the views of others, but it has been pointed out that this was not due to unwillingness to acknowledge the merits of his contemporaries. He was unable to depart from his own methods. It may be noted that Newton rejected two of Huyghen's theories, one of these being the nature of light. Huyghens died at the Hague in 1695, at the age of sixty-six. His career closed an epoch in astronomy which prepared the way for the work of the mightiest intellect which has ever applied itself to the problems of the heavens.

CHAPTER XXXI

NEWTON AND HIS SUCCESSORS

THE work of Kepler prepared the way for the greatest discovery ever made in the history of astronomy. In the first chapter reference was briefly made to the marvellous fact of gravitation. But gravitation is never thought of or spoken of apart from its discoverer. It is "the Newtonian Law." It is never dissociated from the mighty intellect which first revealed it.

Kepler had detected the laws of the planetary motions, but he was unable to show the cause of these motions. The hour had come for the discovery of the fundamental law of the Universe, and with the hour came the man. Isaac Newton, the illustrious astronomer, was the son of a Lincolnshire farmer. Born at Woolsthorpe, near Grantham in 1642, he was sent at the age of twelve to a school at Grantham. At first he was very idle in his studies, but it was not long before he began to take an interest in constructing mechanical models and sundials. One of these dials still remains at Woolsthorpe. When he was fourteen years of age, Newton was removed from the school by his mother, who desired him to become a farmer, hoping that he would now lay aside his books and the studious habits to which he had become addicted. On one occasion Newton was sent in company with an old farm servant to a neighbouring town to sell the products of the farm. The young astronomer, however, preferred to

leave the disposal of the products to his companion, and interested himself in a collection of old books which he had found in a garret.

One of his uncles found him one day sitting behind a hedge reading a book on abstruse mathematics instead of attending to the farm. It was clear that he would not make a good farmer, and his mother, at his uncle's suggestion, wisely resolved to send him to the school to prepare for the University. On June 5, 1660, when he was seventeen years of age, Newton entered the University of Cambridge, and soon afterwards finally turned to astronomy and mathematics. In 1664 and 1665 his excessive study of mathematics brought on ill health, which was intensified by sitting up at night to observe a comet. He made such progress in his studies that in 1669, when in his twenty-seventh year, he was appointed Lucasian Professor of Mathematics at Cambridge.

Among Newton's early studies were his investigations on light. He was much interested in it, and was the first to disperse it in a prism. He showed that white light was actually composed of the seven colours, red, yellow, orange, green, blue, indigo, and violet. But he could never have foreseen the discoveries made in the nineteenth century. He formulated a theory of light opposed to the true view of Huyghens, supposing light to be caused by the emission of minute particles from the celestial bodies. He was so great a man in comparison with Huyghens, that his theory was believed for over a hundred years.

Isaac Newton's researches regarding light prepared the way for the invention of the reflecting telescope. Galileo, as already mentioned, was the first to invent the refractor. It was soon found that as the size of the instrument was increased, the field of view was impaired by a defect known

as chromatic aberration. In fact, the object-glasses, like prisms, dispersed the light into its primary colours. To counterbalance this difficulty, Huyghens and Hevelius made telescopes of enormous focal length; but this could not go on for ever, and Newton, in his investigations on the subject, came to the conclusion that it was impossible to produce a telescope which would be free from chromatic aberration. We know that he was wrong, as several English opticians afterwards succeeded in constructing telescopes free from this defect, and known as achromatic refractors.

Perhaps, however, it was as well for astronomy that Newton erred in regard to the telescope. He determined to make a telescope which did not depend upon refraction, and constructed a concave mirror by a combination of copper and tin which shone with the lustre of silver. He then fixed it at the bottom of a tube, and the images of the stars were examined by means of a magnifying eye-piece. The little telescope was only one inch in diameter, but all the same it distinctly showed the satellites of Jupiter and the phases of Venus. It is now preserved by the Royal Society of London in memory of the great astronomer. This invention was an invaluable boon to science, and gigantic reflectors have since been constructed on Newton's principle by Herschel, Rosse, and other eminent astronomers.

In 1666, as previously mentioned, he began his investigations of the subject of gravitation. Whether the well-known story of the apple is true or not, it is an excellent illustration of Newton's line of reasoning. The story is that, in 1666, as Newton was sitting in his garden at Woolsthorpe, the fall of an apple led him to ask if gravitation, already known to exist on the Earth, and which

caused the apple to fall, did not also hold the Moon to the Earth. The great discovery was made. Having extended gravitation to the Moon, the great astronomer could likewise extend it to the solar system. By this method the Laws of Kepler were shown to be the natural outcome of universal gravitation.

All this may seem very simple, but a great number of difficulties lay before Newton. He could not reconcile several facts regarding the Moon with the theory of gravitation, and he abandoned the subject until 1684. At that time a discussion was proceeding in London between the astronomer Halley, the scientist Hook, and the architect Sir Christopher Wren regarding the movement of a planet according to gravitation. Hook, who was a jealous and vain man, tried to make people believe that he had the solution, but would not give it to the world until, by attempting, people had found out how difficult it was, and would thereby honour the discoverer. Halley, in order to get more light on the subject, asked Newton, who, to his surprise, solved it at once. Halley urged Newton to publish his discoveries regarding universal gravitation. At that time also, new measurements regarding the Moon's distance had removed the difficulties which had hindered the establishment of the law of gravitation. Newton, therefore, published his discoveries in his great work the "Principia," which was given to the world in 1687. In this work he showed the tides also to be the outcome of gravitation. In fact, he announced the great law that "every particle of matter in the Universe attracts every other particle." This discovery was not, however, at once accepted. Huyghens rejected it, though admitting that gravitation ruled the planetary motions. The clergy pronounced it to be impious, and it was a long time before it

was taught in the universities. Still, like all true theories, it triumphed.

It happened that Newton was not a rich man, and was unable to pay for the publication of the "Principia." The Royal Society was also without available funds, and the result was that Halley generously had the book published at his own expense. Halley was Newton's most devoted friend, and their friendship continued without interruption. After the publication of his book Newton speculated in chemistry, but all his labours were lost by an unfortunate accident. One morning he went to church leaving a lighted candle among the papers on his desk. It is said that his pet dog, "Diamond," upset the candle. When the astronomer came home, he found all his papers destroyed. He exclaimed "O Diamond, Diamond! thou little knowest the mischief thou hast done!" His health was impaired by the accident, and, though only about fifty years old at the time, he made no more great discoveries.

In 1687, Newton came prominently before the public. In that year when James II. attempted to infringe on the rights of the University of Cambridge, Newton was one of the nine men who defended the conduct of the University, and won the case. In 1688 he represented the University in Parliament, and for two years retained his seat. At length many of his friends began to think that he should get some honour or appointment. Mr. Charles Montague, a great friend of Newton, was appointed Chancellor of the Exchequer in 1694, and in 1695 he offered the position of Warden of the Mint to the astronomer, who accepted it, his knowledge of physics being of much use to him in his new sphere. In 1697, the position of Master of the Mint fell vacant, and Newton was appointed to that office. He soon found, however, that he could not discharge his

duties both at the Mint and at Cambridge, and in 1701 he resigned his professorship, and severed his connection with the University.

In 1703 Newton was elected President of the Royal Society, a position which he held until the end of his life. In 1705 he was knighted by Queen Anne in recognition of his great discoveries. He now resided in London, and during the remaining years of his life he was chiefly occupied with his duties at the Mint and at the Royal Society, and his mathematical and theological studies. He was deeply interested in theology, being of an extremely religious temperament. On March 20, 1727, Sir Isaac Newton died in London, after a long illness, at the age of eighty-four. A week later he was buried in Westminster Abbey. A magnificent statue was afterwards erected to his memory at Cambridge, where he is represented as holding in his hand a prism. Another memorial to England's greatest astronomer was erected in Lincolnshire in 1858. Considering the vast importance of his discoveries, Sir Isaac Newton was in no way elated. He was always ready to acknowledge what he owed to the great men who preceded him. "If I have seen farther than other men," he said, "it is because I have stood on the shoulders of the giants." His prevailing humility is well expressed by him in his old age, when he compared himself to a little child on the sea-shore gathering pebbles. He had picked one or two from the waves, but the infinite treasures remained undiscovered.

Newton's chief contemporaries, Flamsteed and Halley, were the first and second holders of the office of Astronomer Royal of England. Both were distinguished men. Flamsteed was the elder of the two, and, like Hipparchus and Tycho, was essentially a practical astronomer. His Star Catalogue, constructed at Greenwich, is a standard

work, and has been for many years a book of reference to astronomers all over the world. Flamsteed died in 1719, after a life of usefulness and activity. Halley, who succeeded him, was more of a brilliant genius, and less of a steady observer than Flamsteed. Born in 1656, he was the son of Edmund Halley, a wealthy soap boiler in London. Young Halley from his earliest years showed interest in mechanical invention. He was educated at St. Paul's School, in London, and by the time he left the school he had made much progress in astronomy and mathematics. At the age of seventeen he entered the University of Oxford. At this time he was deeply interested in mathematics, and solved some questions regarding movement in an ellipse; and at the age of nineteen he published a mathematical treatise.

Halley had no intention of being merely an astronomer on paper. He longed to start the practical work of observing. This was an easy matter, for not only was his father wealthy, but he was a wise man; and was anxious that his son should take up the subject in which he was most interested. He therefore gave him an allowance of £300. The young astronomer desired to follow Tycho Brahe's example in determining the positions of the stars with great accuracy. Finding, however, that Flamsteed of Greenwich and Hevelius of Dantzig were engaged on work of the same kind, he determined to visit the island of St. Helena to observe the southern stars, which until then had been neglected.

Halley left Oxford University before taking his degree, and set sail in 1676 when in his twentieth year, in an East India Company ship. Three months later he arrived at St. Helena, having with him a sextant and a telescope 24 feet in focal length. The climate of the island, how-

ever, proving unfavourable, Halley remained for one year only. All the same, he accomplished much valuable work, which gained for him the title of "Our Southern Tycho."

In 1677 the astronomer returned to England, and through the influence of King Charles II. he was made a Master of Arts at Oxford in the following year. In 1678 he was elected a Fellow of the Royal Society, and some time later he was appointed Secretary, an office which he held until he was made Astronomer Royal. In 1679 he visited Germany, in order to represent the Royal Society in a controversy with Hevelius of Dantzig, in regard to the utility of the telescope in the determination of the positions of the stars. Halley remained at Dantzig with Hevelius for a year, and spoke highly of Hevelius' skill as an observer. In 1680 Halley travelled over Europe. He spent much time at the Paris Observatory, at that time directed by Cassini, famous for his satellite discoveries. Halley and Cassini made observations together on the comet of 1680. The English astronomer was very well received in Paris and in all the continental cities. Halley was much interested in the subject of magnetism and the variation of the magnetic needle. In 1692 he put forward a theory of terrestrial magnetism. Twice he took a voyage to the southern seas to observe this variation. In 1694 he set out, but he was obliged to return in 1695 as one of his lieutenants mutinied. In 1699 he again set out, and passed the 52nd degree of latitude. "In these latitudes," he said, "we fell in with great islands of ice of so incredible height and magnitude, that I scarce dare write my thoughts of it." The ice preventing his advance, he finally returned to England in 1700, and published a chart respecting magnetic variation.

In 1684 Halley became intimate with Newton, and indeed it was he who advised Newton to publish his discoveries in regard to gravitation. In December 1684 Halley announced to the Royal Society that Newton was about to write a paper on the subject of gravitation. As has been already explained, the Royal Society was at a very low ebb in regard to funds. At length the Society ordered that Halley "should undertake the business of looking after the book and printing it at his own charge," which he agreed to do.

Reference has been made in the chapters on comets to Halley's greatest discovery, that of the revolution of the comet bearing his name. Another of his great discoveries related to the transit of Venus. He saw that the transits would give astronomers an opportunity of measuring the distance of the Sun from the Earth, and he urged on astronomers the necessity of observing the transit of 1761, which, however, he knew could not occur until many years after his death. His advice was taken by other eminent astronomers who followed him. In 1715 Halley observed the total eclipse of that year, the first which was visible in London since 1140. He observed the eclipse from the rooms of the Royal Society, and left a minute description of the corona.

The death of Flamsteed, which took place in 1719, gave Halley the position of Astronomer Royal, to which he was appointed in 1720. He found no instruments in the Observatory at Greenwich, as those hitherto in use, being the property of Flamsteed, had been removed by his wife, who refused to sell them to Halley on account of unhappy differences which existed between the two astronomers. Not only had Halley no instruments, but he was also without assistance. In 1721 he had a

telescope erected at Greenwich, and then, though sixty-four years of age, he determined to observe the Moon during a period of eighteen years. Halley just lived to complete his observations, which were very useful. His health began to give way in 1739, and he died in 1742, at the age of eighty-five, having survived Newton for fifteen years. He was buried at Lee, in Kent.

James Bradley and James Ferguson, the remaining two men of note among Newton's immediate successors, were each men of distinction in their particular spheres. James Bradley was born at Sherborne in Gloucestershire in 1693. Of his private life there is little to tell. He was educated first at the school of Northleach, and afterwards at the University of Oxford, which he entered in 1711, when in his nineteenth year. While at the University he spent much time with his uncle, the Rev. James Pound, who, although by profession a clergyman, was deeply interested in astronomy and was a well-known observer. It was doubtless through friendship with his uncle that Bradley became expert in the use of astronomical instruments. Bradley and his uncle together investigated the subject of the parallax of the Sun by observing the opposition of Mars. Pound and Bradley showed, as they believed, that the distance of the Sun must be more than 94 millions of miles and less than 125 millions. We now know that they over-estimated the Sun's distance; but, considering their imperfect instruments, it was remarkably near the truth. Halley had evidently a high opinion of Bradley, whose talents were now so widely known that he was elected a Fellow of the Royal Society in 1718. About this time Bradley paid much attention to the eclipses of Jupiter's satellites, which he predicted with much accuracy.

Bradley was originally intended for a clerical career,

and in 1719 the Bishop of Hereford offered him the vicarage of Bridstow in Monmouthshire, to which he was appointed in 1720. But he was only two years in his clerical position. The Savilian Professorship of Astronomy at Oxford—previously occupied by Halley—became vacant by the death of Halley's successor, Keill. At that time it was a rule that the Savilian Professor of Astronomy must not hold a clerical appointment, and there is little doubt that Pound would have been elected had he been willing to surrender his connection with the Church. Bradley, however, expressed his willingness to give up his vicarage, and he was appointed to the Savilian Chair in 1722, when he was twenty-nine years of age. Notwithstanding the awkward and inconvenient instruments with which the Savilian Professor had to conduct his observations, in 1723 he observed the transit of Mercury, and succeeded in measuring the size of Venus; while he made many important observations on the comet of 1723.

The greatest of Bradley's discoveries was made in 1725 and 1726. He was looking for something quite different from what he discovered. From the time of Copernicus, astronomers had made every effort to measure the parallax of the stars, and their inability to do so was long felt as the one drawback to the Copernican system. Bradley made an attempt. He was not successful, but his labours were rewarded by a brilliant discovery—that of the "aberration of light." The astronomer decided to make observations for a year on the star Gamma Draconis, in the constellation Draco, the instrument used being a refractor 24 feet 3 inches in focal length. It was erected in Kew Green, near London, at the house occupied by Samuel Molyneux, afterwards a Lord of the Admiralty, who at one time was greatly interested in astronomy. The

observations in search of parallax were continued for a year. It was found, after much patient observation, that Gamma Draconis was actually displaced in position. But Bradley was not long in finding that the displacement was not due to parallax, as it was of an exactly opposite character. For a long time the astronomer was much perplexed as to the cause of the variation, and he determined to make elaborate investigation of various other stars. He found that all the stars which he observed showed the same displacement.

This phenomenon was not explained by Bradley until some time after the remarkable discovery. It had been discovered before the time of Bradley, by Roemer, that light requires time to travel through space, and it was found that the rate at which it travelled was 186,000 miles a second. Bradley then hit upon the idea that the reason of the displacement was the combined movements of light and the Earth. Thus, as the Earth moved, the stars were displaced in position. This discovery finally confirmed the Copernican theory by showing that the Earth really moved, and it was also of great use in astronomy. Bradley made many experiments to verify his discovery, which was soon placed beyond all doubt. This discovery gained for Bradley the admiration of Newton, who, in his old age, was heard to call him "the best astronomer in Europe."

In February 1742 Bradley was appointed Astronomer Royal of England in succession to Halley. In June 1742 he made his first observation with the transit instrument at Greenwich. The new Astronomer Royal was an extremely energetic man, and it appears that on one day 255 observations were taken by himself alone. By 1747 he had completed the observations which revealed his second great discovery, that of the nutation of the

Earth's axis. It had been known for long that the pole of the Earth is not fixed, and does not point constantly to the same point in the sky. Thus, the star in Ursa Minor which we call the Pole Star will not occupy that position for ever. In the course of 25,000 years the pole will have moved in a great circle through the sky, and will once more point to the Pole Star. During its revolution in the course of 12,000 years the pole will be close to Vega in Lyra. What Bradley discovered was that in the course of nineteen years the position of the pole varied in an extraordinary manner. This was at first thought to be inconsistent with Newton's theory, but Bradley showed it to be due to variable action of the Moon on the matter accumulated round the terrestrial equator.

In 1752 Bradley took a prominent part in the change of the calendar in England. Many years before, the Gregorian calendar had been instituted by one of the Popes and adopted by many of the countries of Europe. In this matter the Roman Catholic Church happened to be right, but England for long refused to accept the new calendar. For his efforts Bradley met with violent opposition. In the words of Mr. Morton, "the people believed that the astronomer was somehow going to rob them of eleven days of their lives, and his decline and death soon after was popularly supposed to be the judgment of Heaven." During the last two years of his life he was subject to a melancholy depression, as he feared that he would survive his mental powers. Probably this depression hastened his death, which took place in 1762.

Newton's theory of gravitation, despite his work and that of his successors, was not at first popular, especially in England. Strange to say, England was not the first country to accept the Newtonian teaching. In Scotland

the law of gravitation was taught earlier than in the sister kingdom, and, indeed, it fell to a Scotsman to popularise fully the Newtonian theory. "Astronomy explained upon Sir Isaac Newton's Principles" was the work of James Ferguson.

James Ferguson was born at Core of Mayen, near Rothiemay in Banffshire, in 1710. His father, John Ferguson, was a poor farm labourer, and James was the second son. The future astronomer had little education. He learned to read unaided, and his father, a man of considerable intelligence, taught him to write. "About three months I afterwards had at the Grammar School at Keith," wrote Ferguson, "was all the education I ever received."

When about seven years of age he became interested in mechanics, and wrote an account of mechanical contrivances. At the age of ten he was sent by his father to keep sheep for a neighbour. While so employed he began to study the stars. When he was fourteen years of age he, to give his own account, "went to serve a considerable farmer in the neighbourhood, whose name was James Glashan. I found him very kind and indulgent; but he soon observed that, when my work was over, I went into a field with a blanket about me, lay down on my back, and stretched a thread with small beads upon it at arm's length between my eye and the stars, sliding the beads upon it till they hid such and such stars from my eye in order to take their apparent distance from one another, and then, laying the thread upon a paper, I marked the stars thereon by the beads according to their respective positions, having a candle by me. My master at first laughed at me, but when I explained my meaning to him, he encouraged me to go on; and that I might make fair copies in the daytime of what I had done in the night, he often worked for me himself."

Thus in the lonely hills of Banffshire the shepherd boy astronomer, encouraged by this kindly farmer, commenced observation of the great orbs of heaven.

Through Glashan, Ferguson became acquainted with higher people about Banffshire, and lived for a time with Thomas Grant, a neighbouring gentleman, whose butler encouraged him in his studies. This man was evidently a good mathematician, and he taught Ferguson algebra and geometry. After his friend left the gentleman's house, Ferguson went back to live with his father, and was employed by a miller about 1731. In the following year Ferguson became acquainted with Sir James Dunbar of Durn, whose sister, being much interested in the young astronomer, took him with her to Edinburgh in 1734. He remained some time in Edinburgh, and while paying a visit to Inverness in 1739 he again became interested in astronomy, and constructed on paper an elaborate diagram of the motions of the Sun and Moon. He also made calculations regarding eclipses of the Sun.

Ferguson returned to Edinburgh in 1741, and two years later finally quitted Scotland for London, taking along with him a mechanical "orrery" representing the movements of the planets, which he constructed in Edinburgh. On his arrival in London, the astronomer became intimate with a gentleman who proposed to get him appointed master of a mathematical school. The plan, however, collapsed, and Ferguson took up the business of drawing pictures and lecturing on astronomy. In the words of Henderson, the author of the "Life of Ferguson"—"with these two professions, Ferguson had a somewhat severe struggle for a living in London for nearly seventeen years."

Although James Ferguson was a great observer, he was not a great mathematician, and to the end of his life he

did not understand Euclid. He had, however, a genius for mechanical invention, and he constructed a large number of orreries, planetariums, etc., representing the motions of the Sun, Moon, planets, and comets. These mechanical models were highly complex in their structure, and we may assert that no astronomer has ever possessed such a genius for representing the movements of the celestial bodies by means of mechanical contrivances as James Ferguson. He likewise constructed astronomical clocks and sundials. In fact, everything connected with observational astronomy was dealt with in these wonderful machines. In 1748 Ferguson commenced his popular lectures, the first subject being the solar eclipse of July 14 in that year. The following year he lectured on other subjects besides astronomy, including mechanics, electricity, optics, &c. In 1751 he constructed his satellite machine, which represented by clockwork the motions of Jupiter's satellites. An excellent illustration of this machine is given in Henderson's work, to which reference has been already made.

Ferguson published in 1754 one of his works, "An Idea of the Material Universe from a Survey of the Solar System," and at this time he was making preparations for his greatest book, "Astronomy explained upon Sir Isaac Newton's Principles," which was published in London in June 1756. During the author's lifetime it went through six editions. Ferguson was now held in universal respect, and his work superseded for a great number of years all other books on astronomy. But he was in very poor circumstances, his sole livelihood being picture-drawing and his lectures. In 1760 King George III. granted to Ferguson an allowance of £50 a year. This pension was given at a critical period in the astronomer's life, when his difficulties almost made him contemplate returning to Scotland. The pension,

however, placed him in a fairly prosperous position, and he lectured at Bristol and at Bath with great popular success. His reputation too increased, and in 1763 he was elected a Fellow of the Royal Society.

In 1761 Ferguson observed the transit of Venus from the top of the British Museum, using a six-foot reflector. He remarked, "I carefully examined the Sun's disc to discover a satellite of Venus but saw none." For some time before the transit he had been taking much interest in it, as it afforded the best means of measuring the Sun's distance. Two years later he sent a paper on his observations to be read before the Royal Society. Year after year the astronomer invented new machines representing the movement of the planets to be exhibited at his public lectures. He also observed the spots on the Sun, and left a drawing of them, while in 1769 he published a description of the transit of Venus of that year, the last of the pair of transits visible during his lifetime.

Ferguson died in London in 1776. His name will for ever be remembered as one who not only made important observations and constructed extraordinary instruments and machines, but as one who did more to make astronomy popular than any astronomer of his day. The greatest service, however, which this man of science rendered was that it was his book on astronomy which started William Herschel on his wonderful career as an observer of the heavens, and for this alone the world can never be sufficiently grateful. But the chief lesson which we learn from the life of James Ferguson is that enthusiasm and perseverance overcome all obstacles. It is surely a striking fact that in the face of tremendous difficulties the humble shepherd boy was destined to do more in popularising astronomy than all his predecessors.

CHAPTER XXXII

THE CONQUEST OF THE STARS

IN the foregoing pages many references have been made to the immortal name of William Herschel, but little has been said of the exact position which Herschel occupies in Astronomy. The astronomers before Herschel occupied themselves only with the solar system —the little group of planets moving round the Sun. Even the mighty mind of Newton was obliged to concentrate on the solar system. The stars were observed certainly, but more as convenient reference points for the observation of the Moon and planets than from the desire of the astronomers to learn anything of the stellar orbs for their own sake. It was reserved for Herschel to commence the conquest of the stars, to start astronomy on a new path. His epitaph claims that "he broke through the barriers of the skies"; and it is no exaggeration to say that this is true. He stands only second to Newton among the pioneers of astronomy. For he led his fellow astronomers, we might say, to a higher pinnacle of knowledge than had ever before been attained, and revealed a vista of Infinity and Eternity unthinkable to the mind of man.

Herschel was born at Hanover on November 15, 1738. He was the third son and fourth child of Isaac Herschel, originally a bandsman, but afterwards the bandmaster of the Hanoverian Guards. Although in humble circumstances, Isaac Herschel was a man of considerable intelli-

gence, an eminent musician, and greatly interested in astronomy. He had a family of ten children, and of these William was by far the most accomplished. He and his sister Caroline, who was twelve years his junior, were the only members of the family who achieved distinction. From the beginning of her life Caroline was deeply attached to her father and her brother William, who were the only two members of the family who showed her invariable affection.

William Herschel attended the garrison school at Hanover until he was fourteen years of age. Here he displayed his love of learning and his brilliant powers by mastering his lessons in half the time taken by his brother Jacob, his senior by four years. William Herschel was a competent musician, and, along with his brother, became an oboist in the Hanoverian Guards, of which his father was bandmaster. The outbreak of the Seven Years' War in 1756 compelled the Hanoverian Guards to fight. Conscription being the rule, the musicians were not exempted from serving their country. After the defeat of the English and the Hanoverians at Hastenbeck in 1757, William Herschel spent the night in a ditch, and, after due consideration, decided that fighting would not be his profession. In fact, with the consent of his father and mother, he deserted and sailed for England, where he arrived when in his nineteenth year. For some time he wandered through England in search of some musical employment, and in 1760 he was appointed to train the band of the Durham Militia. Five years later he became organist at Halifax, and in 1767 in the Octagon Chapel at Bath, where he continued until he became an astronomer. Herschel in 1764 paid a visit to his father, who was now failing, and who died in 1767. His death was a severe blow to Caroline, whose affection was

concentrated on her father and her brother William. Her father had desired to give her a good education, but her mother and her brother Jacob wished her to learn no more than was necessary for the education of a housemaid. After five years William Herschel decided to take his sister with him to England, and she arrived in Bath in August 1772.

At the time when Caroline Herschel arrived in England her brother was beginning to take a deep interest in astronomy. After conducting a concert Herschel would return to his room and study Maclaurin's "Fluxions" and Ferguson's "Astronomy." His original interest in the latter science was due to his father, but the perusal of the work of Ferguson aroused a fresh desire to see for himself the orbs of heaven. As Caroline expressed it: "It soon appeared that my brother was not contented with knowing what former observers had seen." He hired a small telescope, and was so charmed with the wonders of the heavens that he determined to have an instrument for himself. He therefore wrote to London to make inquiries. But the price of the telescope was too great for Herschel with his limited means. The Bath musician, however, was not the man to be baffled by difficulties. He made up his mind to make his own telescope, and, buying the apparatus of a local optician, he succeeded in constructing, after many failures, a reflector, the mirror of speculum metal. On his return from a concert he would plunge with enthusiasm into telescope making, and, while grinding and shaping the mirror, he was obliged to hold his hands on it for sixteen hours at a time, his meals being supplied by his sister, who also read stories to him to break the monotony. But for Caroline Herschel, who spared no trouble for her brother, William would never have become the famous astronomer, and she sacrificed for his sake her prospects as a public singer. In 1774, when

he was thirty-five years of age, Herschel began to observe the heavens with his own telescope.

For seven years Herschel maintained his love for astronomy while pursuing the profession of music. Night after night he swept the skies with various telescopes. Having made one instrument, he determined on seeing more of the celestial wonders, and constructed larger ones. In 1779, through the friendship of Dr. Watson, an eminent literary man, Herschel entered the Literary Society of Bath. In the following year he sent two papers to the Royal Society, followed by another in January 1781. But an event took place which completely changed the current of his life. In 1780 he began a review of the heavens with a 6-inch Newtonian reflector. As he explored the constellation Gemini on the night of March 13, 1781, he observed an object which, unlike the stars, showed a round and well-defined disc, the motion of which was quite perceptible. This discovery of the planet Uranus, mentioned in a previous chapter, was the occasion of much excitement. The Bath musician was at once raised to the rank of an illustrious astronomer. King George III., hearing of Herschel's discovery, summoned him to London in 1782, and conferred on him the title of King's Astronomer, with the small salary of £200 a year. The King likewise pardoned him for his desertion from the army twenty-five years previously. Herschel now cut himself adrift from the profession of music, and he and his sister settled at Datchet, near Windsor, in August 1782. He was then forty-four years of age.

William and Caroline Herschel removed in 1786 to Slough, near Windsor—"the spot of all the world," wrote Arago, "where the greatest number of discoveries have been made"—and the astronomer remained there for the

rest of his life. From dusk to dawn he swept the heavens with his mighty reflectors, in the mirrors of which the stars appeared to move in a glorious procession. He discovered many star clusters, over two thousand nebulæ, and about seventy million stars. In 1787 Caroline Herschel was appointed his assistant with a salary of £50 a year. She would sit beside her brother, who would dictate to her what he saw. Sometimes, she tells us in her memoirs, the ink froze in her pen. Miss Clerke thus describes Herschel's enthusiasm: "The thermometer might descend below zero, ink might freeze, mirrors might crack, but provided the stars shone he and his sister worked on from dusk till dawn."

"While Herschel was thus rapidly rising into fame," writes Mr. Sime in his admirable biography of the great German astronomer, "he was not forgetful of the sister who so generously sacrificed her own wishes and prospects as a singer to advance his as an astronomer." He presented Caroline with a five-foot reflector, with which she explored the skies. She discovered a number of clusters and nebulæ and detected eight comets—one of which is now known as Encke's—between 1786 and 1797. Von Magellan, a foreign astronomer, reported in 1786 that the brother and sister were equally interested in astronomy.

The University of Edinburgh conferred on Herschel in 1786 the degree of LL.D.; in 1792 he received the freedom of Glasgow, and in 1816 he was created a knight of the Royal Hanoverian Guelphic Order. Five years later he became the first President of the Royal Astronomical Society. But he cared little or nothing for honours. He was described as "a man without a wish that has its object in the terrestrial globe." Like Newton, he was in no way elated with his wonderful discoveries. Writing to his

sister from London in 1782 he said, "Among opticians and astronomers nothing now is talked of but what they call my great discoveries. Alas! this shows how far they are behind, when such trifles as I have seen and done are called great."

Advancing years in no way affected Herschel's wonderful mind. But his duties as King's Astronomer necessitated his acting as what Mr. Sime calls "showman of the heavens" on the visits of royalties to Windsor, often after a whole day's work, when rest was absolutely necessary. This tremendous strain, which reflects little credit on the Court, proved too much for the old man. His health began to give way, although his mind was as vigorous as ever. As Miss Clerke puts it: "All his own instincts were still alive, only the bodily power to carry out their behests was gone. An unparalleled career of achievement left him unsatisfied with what he had done. His strong nerves were at last shattered." After a prolonged period of failing health he died at Slough at the age of eighty-three on August 25, 1822. His sister survived him for twenty-five years, dying early in 1848 at the advanced age of ninety-seven.

The son of the Hanover bandmaster was, in the truest sense, the founder of sidereal astronomy. He observed the suns which spangle the sky to discover the secrets of their constitution. He aroused by his brilliant discoveries widespread interest in the star depths. His career stimulated astronomical research during the nineteenth century. This may be seen from a study of the astronomical work of the past hundred years. The great work of Herschel has somewhat overshadowed his successors, many of whom have been men of the most brilliant genius. Contemporary with him were such men as Laplace and Olbers; among his immediate successors we find the great names

of Bessel, Struve, and Henderson; in the middle of the century Le Verrier and Adams; while in more recent times the astronomical army has been led to still greater triumphs by such men as Secchi, Huggins and Vogel, Schiaparelli and Newcomb, and many other devoted students of Nature. Thus, while the Romance of Astronomy belongs in the first place to the heavenly bodies themselves, there is something no less romantic in the study of the labours of that noble band of men who have dared to sound the Universe and conquer the unknown.

CHAPTER XXXIII

A FINAL SURVEY

IN the preceding chapters we have dealt with the Universe as we know it to-day, and with the means by which astronomers have reached their conclusions. The science of astronomy is in many ways the grandest of all the sciences, for it has enlarged our knowledge a thousand-fold, a million-fold, beyond all the other sciences. It leads us to look outwards by means of the telescope and the spectroscope into mighty vistas in space, and to look backwards in imagination over enormous vistas of time. Schiaparelli has called astronomy the science of Infinity and Eternity, and this phrase exactly describes the modern development of the science of the heavens. On all sides the astronomer deals with the Infinite and the Eternal.

The romance of modern astronomy consists in great part in the enormous extension of our knowledge of the visible Universe. As a distinguished writer has well said, "Compared with the fields from which our stars fling us their light, the Cosmos of the ancient world was but as a cabinet of brilliants, or rather a little jewelled cup found in the ocean or the wilderness. Wonderful as were the achievements and sagacious as were the guesses of the Greek astronomers, they little suspected what they were registering when they drew up their catalogues of stars." To the ancients the Earth was the centre of the Universe, fixed and immovable, the end and aim of

the entire creation. Round the Earth revolved the Moon, the Sun, the planets, each in their own particular complicated pathways, and, farther away, the fixed stars, which they believed to be points of light fastened to the inside of a sphere. What lay beyond was outside the Universe. The whole Universe was supposed to be small in extent; its size was quite easily grasped by the mind of man. The Universe, too, in the opinion of the ancients, was created purely for the benefit of the Earth's inhabitants, the Sun to give light and heat, and the Moon to illuminate the nights, while the stars were regarded as convenient secondary light-givers in the absence of the Moon.

What a contrast between these views and the truths with which we are acquainted to-day through modern astronomy. So far from being the centre of the Universe, the Earth is not even the centre of the planetary system; so far from being the largest and most important body in the Universe, it is merely what we might call the second-rate satellite of a second-rate star. So far from the dimensions of the Universe being conceivable, they are absolutely inconceivable. The solar system alone is nearly five thousand millions of miles in diameter, and the solar system is a mere point in comparison with the greater system of the stars.

No less remarkable than the enlargement of the Universe in space has been its enlargement in time. To the thinkers of the Middle Ages a few thousand years contained the life history of the Universe. Stars and Suns were all brought into existence six thousand years ago. Beyond nothing was known. Modern astronomy has pushed back the beginning of things into the vista of the past. Millions of years, tens of millions of years, take the place of thousands. By observations on the heavens, by reasoning on

these observations, astronomers trace processes which require millions of years for their completion. Astronomy is indeed the science of Eternity. Not only so, it shows that there is in reality no such thing as time, that it is a purely relative conception, due to our position on a little planet revolving round a star.

Our subject in the preceding pages has been the romance of modern astronomy, and nothing could be more romantic than the steady development of our knowledge, till to-day we know the Universe, not as the little "corner" which it appeared to our forefathers, but as Infinity itself. A brief survey may be taken of the journey which we have traversed in imagination in the preceding pages. Naturally the mind of man, in its journey through the Infinite, begins with the Earth, our dwelling-place. By the revelations of astronomy, we behold the Earth as a globe rotating rapidly on its own axis, and in ceaseless revolution round the Sun, on whose beams it depends for its existence as an abode of life.

At a distance of 238,000 miles we come upon our faithful satellite the Moon, the only one of the celestial bodies which revolves round the Earth. The Moon is the Earth's peculiar possession. As has been seen, it is a "detached continent," probably literally as well as metaphorically. And we perceive, too, that the life of the Moon as a world is long since ended; it is a closed chapter in the book of time. Modern astronomy shows us that, as Flammarion puts it, "in space there are both cradles and tombs." The Moon is one of the tombs of the Universe.

Then our study of the Earth and Moon shows that the Earth and Moon form by themselves a little system—the Earth-Moon system or Terrestrial system, as it is variously called—within the greater solar system. In the Earth-

Moon system our scale of measurement is thousands of miles; in the solar system we have to measure by a new scale—millions of miles. In the middle of the system we see the mighty Sun, whose diameter is a hundred times that of the Earth, rotating slowly on its axis and holding sway over a system of planets of all sizes, and, in addition, controlling the motions of the comets and meteoric systems. Examples have been given of the power of the Sun, of the storms raging in its atmosphere, of the sea of fire which surrounds it, and of the atmospheric catastrophes which give rise to the mighty spots or rents in the glowing atmosphere. Reasoning has shown us the enormous age of the Sun—that millions of years may elapse and make little change on the orb of day. So far as the inhabitants of the Earth are concerned, the Sun is eternal.

Round the Sun we see revolving the planets, divided into the three well-defined groups. First, we have the inner planets, of which our Earth holds the proud position of chief world, revolving at distances which vary from 36 millions to 141 millions of miles. This group includes swift little Mercury, whirling round the Sun with an enormous velocity, followed by Venus, then the Earth, and next Mars. Next we have the asteroids, the miniature worlds which fill the space between the pathways of Mars and Jupiter. Thirdly we have the outer planets, revolving at distances varying from 484 millions to 2700 millions of miles—Jupiter with its retinue of eight satellites, Saturn with its more wonderful system of ten attendant worlds and three revolving rings, Uranus with its four moons, creeping along at a comparatively leisurely pace, and, finally, distant Neptune, the exile of the solar system, circling round the known boundaries of the solar system with one faint attendant. Across this enormous system,

with a diameter of over five thousand millions of miles, the rays of light flash in eight hours. How vast is the system, how unthinkable are its dimensions, how unfathomable its depths; and how wonderfully is it regulated by that Divine Ordinance of Nature, the law of gravitation.

To the mind of the ancient astronomers a system so vast, as we know the solar domain to be, would have seemed Infinity itself. They would have been unable to conceive so great a revelation of Immensity. Yet, when we come to study the stars, a new truth dawns on our minds that just as the Earth and Moon form by themselves a little system within the greater solar system, so the solar system itself, containing many lesser systems, is also but a little system within a greater—the system of the stars. In the Earth-Moon system the scale is thousands of miles. In dealing with the solar system we are obliged to use a new scale—a scale of millions of miles; and when we come to consider the universe of the stars, this scale itself is quite inadequate. The scale is one of billions and hundreds of billions of miles.

So, too, in regard to the motion of light, a second and a half is required for light to pass from the Moon to the Earth. The scale of light-velocity for the Earth-Moon system is seconds. For the solar system that scale is minutes and hours, and for the stellar system years and centuries.

In his "Popular Astronomy" Flammarion brings home very vividly the isolation and minuteness of the solar system in the greater system of the stars. On a journey through space in imagination the French astronomer writes: "The Sun himself, with all his immense system, has sunk in the Infinite night. On the wings of inter-sidereal comets we have taken our flight towards the stars, the suns of space.

Have we exactly measured, have we worthily realised the road passed over by our thoughts? The nearest star to us reigns at a distance of about twenty-five billions of miles; out to that star an immense desert surrounds us the most profound, the darkest and the most silent of solitudes. The solar system seems to us very vast; relatively to the fixed stars, however, our whole system represents but an isolated family immediately surrounding us: a sphere as vast as the whole solar system would be reduced to the size of a simple point if it were transported to the distance of the nearest star. The space which extends between the solar system and the stars, and which separates the stars from each other, appears to be entirely void of visible matter, with the exception of nebulous fragments, cometary or meteoric, which circulate here and there in the immense void. Nine thousand two hundred and fifty systems like ours would be contained in the space which isolates us from the nearest star."

When we come to contemplate the system of the stars, to journey through it in imagination, we see our Sun from a new point of view. It is merely a star moving through space, and carrying with it planets, satellites, and comets. All the stars are in motion, some rushing through space with almost inconceivable velocity, others moving at a slower pace, but all rushing onwards at a speed to which we on Earth are quite unaccustomed. There are in the system of the stars, so far as we know, about 500 million stars. In addition to those bodies modern astronomy has revealed to us thousands of the luminous masses known as nebulæ, which form the materials out of which finished systems of suns and planets are wrought by the Divine power in the course of ages. Then astronomy shows us the possible shape of the starry system. It tells us of the

Galaxy, that mighty region of clustering orbs, the equator of the starry globe, and it indicates that the starry system, like the solar system and the smaller satellite systems, is merely a system within a greater. But what that greater system consists of and how far it extends the mind of man cannot tell. Even of this mighty system of the stars itself our knowledge is limited; we do not know whether or not it has a central body; we do not know the precise distance to which it extends; we only can say that the more distant stars of the Milky Way are placed at a distance so great that it is almost impossible to express them on the scale of miles. On the scale of light we can estimate that the light rays which dart from the Moon in a second and a half, and cross the diameter of the solar system in eight hours, require thousands of years to span the mighty void.

The romance of astronomy can guide us no further. On the threshold of a vaster system we pause, and only speculation and theory can take us beyond; but how vast a field of space has modern astronomy revealed to us! "Eternity," says Flammarion, "is the field of the Eternal Sower." Throughout space we behold stars and systems in every stage of evolution, nebulous masses, clustering stars, finished suns and systems, decrepit worlds, and, finally, dead and dark stars. The Eternal Purpose of Evolution is at work throughout the depths of space. The Divine Will is in constant operation while suns and systems are being fashioned and nebulous matter being brought into new existence.

What a vast and mighty Universe modern astronomy reveals to the mind of man, a Universe without bounds, without beginning or end in time, a Universe in which the Earth is but an absolutely insignificant atom, "a globule

lost in the Infinite night." As Flammarion puts it, "In the eternity of duration the life of our proud humanity, with all its religious and political history, the whole life of our entire planet is but the dream of a moment."

It is at this point, the last of the great truths which we learn from the romance of astronomy, that the minds of many get disturbed. Some sigh for the old ideas of a compact Universe and a history of a few thousand years, thinking it more conducive to religious faith; others by accepting these sublime truths believe their faith shaken by the marvels which science has revealed. These attitudes are both mistaken ones. Although the romance of astronomy ends when the most distant star is reached, it has some bearing on the greater problems and the higher thought of men. Modern astronomy has revealed to us a Universe infinitely vaster than was known to our forefathers; it has correspondingly widened and exalted our knowledge of the Creator of all things. Not only has modern astronomy done this, it has also shown the marvellous height which may be reached by the human mind, chained to a little revolving globule lost in the rays of a star, yet able to span the vast spaces of the Universe, to weigh the stars, to predict the celestial motions; it has given us a deeper appreciation of the dignity of the human intellect which can soar above its environment into the regions of things divine and eternal.

We read much in the Bible of the Infinite and the Eternal, chiefly as attributes of God. Astronomy gives examples of Infinity and Eternity and leads us to a higher plane of thought and of religion. The romance of astronomy is more romantic than any romance, more fascinating than any story. By its means we are brought

face to face with Infinity and Eternity, and after a study of the wonders which it reveals to us, we can only repeat with deeper reverence the words of the Psalmist:—

"Thine, O Lord, is the greatness, and the power, and the glory; for all in heaven and earth is Thine."

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